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Planning in children with Autism Spectrum Disorder: The role of verbal mediation

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Abstract

This study examined verbal mediation during planning in school-age children with autism spectrum disorder (ASD) relative to age- and nonverbal IQ- matched typically developing peers using a dual-task paradigm. Analyses showed no group differences in performance. However, in the condition intended to disrupt verbal mediation, language skills were associated with planning performance for the TD group, but not the ASD group. Upon examining ASD subgroups with versus without comorbid structural language impairment, children with ASD and normal language appeared to rely on verbal mediation to a greater degree than children with ASD and language impairment, but to a lesser degree than TD peers. Thus, the role of verbal mediation in planning for children with ASD differs depending on language status.

Keywords

Autism Spectrum Disorder; Executive Function; Planning; Language

Introduction

Executive function (EF) refers to a set of cognitive processes involved in goal-directed behavior that are linked to long-term academic, social, and emotional outcomes (Best, Miller, & Naglieri, 2011; Blair, 2002; Friedman et al., 2007; Moffitt et al., 2011; Riggs, Blair, & Greenberg, 2003; Simonds, Kieras, Rueda, & Rothbart, 2007). Deficits in EF have been extensively documented in children with autism spectrum disorder (ASD; Edgin & Pennington, 2005; Ellis Weismer, Kaushanskaya, Larson, Mathée, & Bolt, 2018; Kenworthy, Yerys, Anthony, & Wallace, 2008; Landa & Goldberg, 2005; Ozonoff, Pennington, & Rogers, 1991; but see Bogte, Flamma, Van Der Meere, & Van Engeland, 2009). In fact, individual differences in EF ability predict school readiness (Pellicano et al., 2017), and long-term social and behavioral outcomes in children with ASD (Vogan et al., 2018). Complex EF tasks, like planning, appear to be especially problematic for children with ASD

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(Diamond, 2013; Joseph, McGrath, & Tager-Flusberg, 2005; Unterrainer et al., 2016), potentially due to diminished use of language to regulate goal-directed behavior (Holland & Low, 2010; Joseph et al., 2005; Marcovitch & Zelazo, 2009; Wallace, Silvers, Martin, & Kenworthy, 2009).

According to the Hierarchical Competing Systems Model (Marcovitch & Zelazo, 2009; Zelazo, 2004), language in the form of verbal mediation (i.e., inner speech, self talk) supports and facilitates higher-order executive function skills. Consistent with this view, researchers have hypothesized that individuals with ASD may have diminished use of verbal mediation, which in turn, may contribute to their difficulties with EF (Joseph et al., 2005; Russell-Smith, Comerford, Maybery, & Whitehouse, 2014; Whitehouse, Maybery, & Durkin, 2006; Winsler, Abar, Feder, Schunn, & Rubio, 2007), particularly with planning abilities (Holland & Low, 2010; Wallace et al., 2009; Williams, Bowler, & Jarrold, 2012). Indeed, prior work has shown a link between verbal mediation and EF in children with ASD (Joseph et al., 2005; Russell-Smith et al., 2014). However, while some investigations have shown diminished use of verbal mediation in children with ASD (Holland & Low, 2010; Kercood, Grskovic, Banda, & Begeske, 2014; Wallace et al., 2009), others have shown no differences between groups (Williams et al., 2012; Winsler et al., 2007). Furthermore, the evidence is mixed as to whether diminished use of verbal mediation negatively affects performance in children with ASD (Joseph et al., 2005; Kercood et al., 2014; Russell-Smith et al., 2014; Williams et al., 2012; see Williams, Peng, & Wallace, 2016 for a review). It is possible that discrepancies between studies relate to the differences in the degree to which task demands are verbal in nature (Ellis Weismer et al., 2018; Van Eylen, Boets, Steyaert, Wagemans, & Noens, 2015). They may also relate to variability in language status within ASD groups, such as the presence of comorbid language impairment (Ellis Weismer et al., 2018; Kjelgaard & Tager-Flusberg, 2001; Wittke, Mastergeorge, Ozonoff, Rogers, & Naigles, 2017). The current study addresses these issues by examining the role of verbal mediation in planning performance on a task with minimal verbal demands in school-aged children with ASD, subgrouped by language status, relative to typically-developing (TD) peers.

EF and Language

The term EF refers to a set of cognitive processes that control and regulate behavior. Lower-level processes falling under the umbrella of EF include inhibition, updating of working memory, and task switching (i.e., shifting; Diamond, 2013; Miyake et al., 2000; Smith & Jonides, 1999; Zelazo & Frye, 1998). Higher-order processes, such as planning and reasoning, also fall under the umbrella of EF and involve coordination of lower-level EF components (Diamond, 2013; Miyake & Friedman, 2012). The Hierarchical Competing Systems Model (HCSM; Marcovitch & Zelazo, 2009; Zelazo, 2004) posits that language underlies developmental advancement in EF skills. With maturation, typically developing children are thought to begin using verbal mediation (i.e., self-generated labeling, inner speech) to resolve conflict, and to construct and use the embedded rule structures that underlie goal-directed behavior (Marcovitch & Zelazo, 2009; Zelazo, Carter, Reznick, & Frye, 1997; Zelazo & Frye, 1998). Initially, children use language in the form of self talk to guide goal-directed behavior. By middle childhood, self talk becomes internalized in the form of verbal mediation (i.e., inner speech; Fatzer & Roebers, 2012; Fernyhough & Fradley, 2005; Vygotsky, 1987; Winsler, Fernyhough, & Montero, 2009). In typical development, prior work has demonstrated a facilitative effect of language in the form of verbal mediation on EF performance (Alarcón-Rubio, Sánchez-Medina, & Prieto-García, 2014; Baldo et al., 2005; Fatzer & Roebers, 2012; Gruber & Goschke, 2004; Kirkham, Cruess, & Diamond, 2003; Yerys & Munakata, 2006).

EF and Language in ASD.—Children with ASD have core deficits in social communication and restricted and repetitive interests and behaviors (American Psychiatric Association, 2013), as well as deficits in EF skills (Christ, Kester, Bodner, & Miles, 2011; Ellis Weismer et al., 2018; Kercood et al., 2014; Pellicano et al., 2017; Van Eylen et al., 2015; but see Bogte et al., 2009). One prominent cognitive account of autism, the executive dysfunction account, suggests that these deficits in EF underlie other aspects of the ASD profile, such as difficulty switching attention, tendency to perseverate, and lack of impulse control (Hill, 2004; Joseph et al., 2005; Ozonoff et al., 1991). Although more recent work shows that this theory does not fully explain the ASD profile (e.g. Leung & Zakzanis, 2014; Pellicano, 2011), there are robust findings of deficits in lower-level EF skills, such as shifting (Kaland, Smith, & Mortensen, 2008; Pellicano, 2010; Semrud-Clikeman, Fine, & Bledsoe, 2014) and inhibition (Christ et al., 2011; Pellicano et al., 2017; Van Eylen et al., 2015). Unsurprisingly, difficulties with higher-order EF skills, such as planning and problem solving, in individuals with ASD have also been observed (Diamond, 2013; Joseph et al., 2005; Unterrainer et al., 2016).

Researchers have suggested that diminished use of language in the form of verbal mediation to regulate behavior may relate to EF difficulties in children with ASD (Bíró & Russell, 2001; Holland & Low, 2010; Joseph et al., 2005; Russell, Jarrold, & Hood, 1999; Wallace et al., 2009; Whitehouse et al., 2006). Studies testing this hypothesis have yielded discrepant results. Joseph and colleagues (2005) tested school-aged children with ASD relative to verbal- and nonverbal- IQ matched TD peers on several measures of EF – working memory, inhibition, and planning – using standardized measures. The authors found superior performance in the TD group relative to the ASD group across measures, and associations between EF performance and language in the TD group, but not in the ASD group. The authors interpreted these findings to suggest that children with ASD may not use verbal mediation strategies to regulate goal-directed behavior (see also Kercood et al., 2014). Conversely, other researchers have shown a different pattern of results (Russell-Smith et al., 2014; Russell, Jarrold, & Henry, 1996; Williams, Happé, & Jarrold, 2008; Winsler et al., 2007). Winsler and colleagues (2007) assessed self talk during executive function tasks (e.g., shifting, planning) in high-functioning children with ASD relative to TD peers, and found no group differences in overt self talk during performance. In fact, children with ASD performed better when using overt self talk than when they were silent, whereas TD peers did not evidence this pattern.

These inconsistent findings in the literature regarding the association between verbal mediation and EF performance in individuals with ASD may relate to the different approaches to measuring EF and verbal mediation. First, different EF tasks may elicit distinct uses of verbal mediation. For instance, Whitehouse et al., (2006) tested children with

ASD on a short-term memory task where children were required to recall serially presented pictures, and found that individuals with ASD had limitations in their use of verbal mediation. Alternatively, Russell et al., (1996) found that the group with ASD was as likely as the comparison group to employ verbal mediation on a working memory task. Considering that the difficulty level of a given task may dictate whether verbal mediation is unnecessary (i.e., the task is too easy) or unhelpful (i.e., the task is too difficult; Alderson-Day & Fernyhough, 2015; Fernyhough & Fradley, 2005; Vygotsky, 1987), it is possible that the more challenging working memory task in Russell et al. (1996) elicited verbal mediation to a greater degree than the less-complex short-term memory task in Whitehouse et al. (2006). Second, different measures of verbal mediation likely yield different results. Whitehouse et al. (2006) compared short-term memory performance in a condition requiring overt self talk (i.e., labeling a recall item) to a condition without this requirement and to a condition thought to suppress verbal mediation (i.e., articulatory suppression secondary task). Their findings indicated poorer use of verbal mediation to regulate performance in children with ASD relative to TD peers. In contrast, Winsler et al. (2007) tested children with ASD on a card-sorting task and found that overt self talk (i.e., externalized verbal mediation) during performance in the ASD group was similar to the TD comparison group, suggesting no group differences in verbal mediation. Although the authors concluded that their participants with ASD did not have a deficit in verbal mediation, this investigation is limited by the lack of *internalized* verbal mediation measurement. Based on their ages (7–18 years), most of the participants in Winsler et al. (2007) would be expected to have fully internalized verbal mediation (Fernyhough & Fradley, 2005; Vygotsky, 1987).

These discrepant findings may be reconciled by testing the relationship between verbal mediation and EF performance on an EF task that involves multiple EF components, like planning (Miyake & Friedman, 2012). Since several cognitive processes have been implicated in planning abilities (Asato, Sweeney, & Luna, 2006; Bull, Espy, & Senn, 2004; Miyake et al., 2000), it is likely a more optimal measure than measures of lower-order EF skills (e.g., inhibition) to test the contributions of verbal mediation as verbal mediation is likely to be facilitative of performance on this complex task. Another way to address inconsistency in results is to use a dual-task paradigm to test the use of either externalized or internalized verbal mediation, similar to that used by Winsler et al. (2007). In this paradigm, participants perform a secondary verbal task concurrently with the primary task under the assumption that the secondary task prevents verbal mediation. Articulatory suppression is a commonly employed secondary verbal task, and it involves asking participants to repeat a familiar word (e.g., *Monday*) while completing the primary task. If performance costs relative to baseline are observed on the primary task in the articulatory suppression secondary task condition, then the facilitative effects of verbal mediation on the primary task are assumed to have been disrupted. Numerous studies have employed dual-task paradigms to assess verbal mediation in individuals with ASD (e.g., Altgassen, Schmitz-Hübsch, & Kliegel, 2010; Russell-Smith et al., 2014; Whitehouse et al., 2006), and a few of these studies focus specifically on planning (Holland & Low, 2010; Wallace et al., 2009; Williams et al., 2012).

Planning skills in ASD

Planning is a higher-order, complex EF. It involves a sequence of planned actions that are constantly monitored, re-evaluated, and updated. Secondary to its complex nature, several lower-level EF processes are implicated in planning abilities, including inhibitory control (Asato et al., 2006; Zook, Davalos, DeLosh, & Davis, 2004), working memory (Gilhooly, Phillips, Wynn, Logie, & Della Sala, 1999; Miyake et al., 2000), and shifting (Bull et al., 2004). The most frequently used planning tasks are Tower tasks, like the Tower of London (ToL) or Tower of Hanoi, which involve participants moving objects on pegs from an initial to a final configuration (Gangopadhyay et al., 2018; Holland & Low, 2010; Larson et al., 2019; Williams et al., 2016). Task difficulty varies according to the minimum number of moves required to reach the final configuration. In these tasks, planning performance may be quantified by measures that capture accuracy and time spent engaging in the task. The number of moves a participant uses to complete each planning problem (i.e., each trial) is a measure of overall accuracy. Planning time is the time from the onset of a trial to the time when the participant initiates their first move. Planning time is thought to be sensitive to the use of verbal mediation to plan behavior prior to the participant beginning to solve the problem. Execution time may be measured in two ways: a) the total time to complete a trial once the participant has initiated their first move, or b) the total time to complete a trial from trial onset (i.e., as soon as the participant sees the problem) to the participant's final move. Execution time is thought to reflect visuospatial strategies used to complete the task, particularly after the participant has initiated their first move (Kaller, Rahm, Spreer, Mader, & Unterrainer, 2008; Larson et al., 2019).

Planning has been considered a robust deficit in ASD (Bennetto, Pennington, & Rogers, 1996; Booth, Charlton, Hughes, & Happé, 2003; Joseph et al., 2005; Ozonoff & Jensen, 1999; Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009). However, there are several studies demonstrating intact planning abilities in ASD (Happé, Booth, Charlton, & Hughes, 2006; Just, 2007; Landa & Goldberg, 2005; Ozonoff, South, & Miller, 2000; Pellicano, Murray, Durkin, & Maley, 2006). It is possible that discrepancies between studies relate to the role of verbal mediation in planning performance (Marcovitch & Zelazo, 2009; Russell, 1997; Russell et al., 1999).

The Role of Verbal Mediation in Planning in ASD.

Investigations that have explored the role of verbal mediation in planning performance of individuals with ASD under dual-task conditions have often used the ToL task (Shallice, 1982). Wallace et al. (2009) examined planning performance of adolescent participants with ASD and full-scale IQ-matched TD peers on the ToL in no-secondary task and concurrent articulatory suppression secondary task conditions. The interaction between group and condition was not significant, indicating no group difference in the degree to which performance suffered in the articulatory suppression condition relative to the no-secondary task condition. Yet, post-hoc within-group comparisons suggested that planning was less verbally mediated in ASD than in TD peers. Williams et al. (2012) showed that ToL performance of adults with ASD suffered significantly less than the performance of age-, verbal IQ-, performance IQ-, and full-scale IQ- matched TD peers in the articulatory suppression condition relative to the no-secondary task condition. Taken together, these studies suggest that planning may be less verbally mediated in individuals with ASD than typical individuals. Notably, Williams et al. (2012) also showed that the ASD group did not perform significantly worse than the TD group in the no-secondary task condition, contradicting previously-reported planning deficits in ASD. It is possible that failure to use language in the form of verbal mediation to regulate performance may not negatively impact performance in children with ASD to the same degree as TD peers.

Holland & Low (2010) is the only prior study to examine the role of verbal mediation in planning execution time using a dual-task paradigm with a nonverbal suppression condition. This condition controls for the additional cognitive load imposed by the secondary articulatory suppression task relative to the no-secondary task condition by requiring participants to complete a concurrent nonverbal suppression secondary task (e.g., simple foot tapping, tapping in a repeated sequence). Holland and Low (2010) tested children with ASD and TD peers matched on age (ages 9–11), verbal mental age, and numerical reasoning ability on the Tower of Hanoi (i.e., similar to the ToL) under no-secondary task, articulatory suppression, and nonverbal suppression (i.e., tapping in a repeated sequence) conditions. Articulatory suppression did not affect performance relative to the no-secondary task condition in the ASD group, but did negatively affect performance in the TD group. Nonverbal suppression relative to the no-secondary task condition affected groups similarly. However, only results on total time to complete trials are reported. Thus, Holland and Low's (2010) results align with prior work suggesting diminished verbal mediation in the ASD group (Wallace et al., 2009; Williams et al., 2012), but do not provide evidence on accuracy or time spent planning separate from trial completion time on the ToL.

Investigations of planning in children with ASD are limited by several factors. First, the ToL (or Tower of Hanoi) tasks used in these studies varied in task characteristics, such as trial types and the degree of verbal versus nonverbal task demands. Holland and Low (2010), specifically, analyzed a single, identical ToL problem across conditions, which may have resulted in unintended learning effects (Williams et al., 2016). Additionally, the verbal versus nonverbal nature of task demands may relate to the manner in which language is drawn upon to complete the task (Marcovitch & Zelazo, 2009; Williams et al., 2016). A task with high verbal demand may confound the relationship between verbal mediation and performance to a greater degree than a task with low verbal demand (Ellis Weismer et al., 2018; Larson, Gangopadhyay, Kaushanskaya, & Weismer, 2019). Highly verbal EF tasks may also overestimate the severity of EF deficits in individuals with language impairments, such as in children with ASD and comorbid language impairment (Ellis Weismer et al., 2018; Kjelgaard & Tager-Flusberg, 2001; Wittke et al., 2017). Second, while prior work using a dual-task paradigm to examine planning in ASD has measured accuracy (e.g., Wallace et al., 2009; Williams et al., 2012). Holland and Low (2010) is the only study to examine the time participants require to complete trials. Nevertheless, Holland and Low (2010) conflate planning and execution time rather than accounting for planning and execution time separately. Planning time likely reflects the degree to which participants use verbal mediation whereas execution time likely reflects visuospatial strategy use (Kaller, Rahm, Spreer, Mader, & Unterrainer, 2008; Larson et al., 2019).

Finally, no prior research on planning in children with ASD has reported on a subgroup of children with ASD and comorbid structural language impairment (Ellis Weismer et al., 2018; Kjelgaard & Tager-Flusberg, 2001; Wittke et al., 2017). That is, children with ASD with structural language ability in the normal range and children with ASD with structural language impairment have not been examined as distinct groups even though variability in language ability is widely documented in ASD (Ellis Weismer et al., 2018; Haebig, Saffran, & Ellis Weismer, 2017; Norbury et al., 2017; see Tager-Flusberg, Paul, & Lord, 2005 for a review). This issue has important theoretical and empirical considerations. The Hierarchical Competing Systems Model posits an important relationship between language and EF in typical development (Marcovitch & Zelazo, 2009), and it follows that deficits in language may affect this relationship. Moreover, there is empirical evidence of differences in the relationship between language and lower-level EF performance (e.g., inhibition, shifting) in children with ASD with structural language impairment relative to children with ASD without structural language impairment (Ellis Weismer et al., 2018). In children with structural language impairment without ASD, there is evidence of poorer planning performance relative to TD peers (Abdul Aziz, Fletcher, & Bayliss, 2017; Lidstone, Meins, & Fernyhough, 2012; but see Marton, 2008). Using a dual-task paradigm, Larson et al. (2019) examined performance on a version of the ToL with minimized verbal demands in children with Specific Language Impairment relative to TD age-matched peers. Though results showed comparable accuracy between groups, there were group differences in the relationship between language and planning performance when verbal mediation was disrupted (i.e., under articulatory suppression). It is possible that children with ASD and a structural language profile similar to children with Specific Language Impairment will present with differences in the relationship between language and planning performance relative to children with ASD and structural language ability in the normal range. However, no prior work addresses these relationships in children with ASD subgrouped according to language status.

Current study

In the present study we asked whether children with ASD differ from age- and nonverbal IQ- matched TD peers in planning performance on the ToL overall and in how verbal mediation is used during planning performance. We examined the role of verbal mediation in planning via a dual-task paradigm: no-secondary task (i.e., baseline), articulatory suppression secondary task (i.e., verbal mediation disruption), and motor suppression secondary task (i.e., secondary task cognitive load control) conditions. Our version of the ToL used one level of difficulty – 4-move problems – and verbal demands within the task were minimized to the extent possible. We hypothesized that if planning is verbally mediated in the ASD group, we should observe similar patterns in the ASD and TD groups. First, articulatory suppression should detrimentally affect planning performance on the ToL compared to the no-secondary task and motor suppression conditions. Second, language skills should be related to performance across conditions, particularly with time spent planning prior to engaging in the task. If planning is not verbally mediated in the ASD group, then articulatory suppression should have relatively little impact on ToL performance over and above the additional cognitive load imposed by the secondary task (i.e., no difference between secondary task conditions) and there should be little association between language skills and performance. We hypothesized that the ASD subgroups with versus without structural language impairment would show different patterns of relationships between language and performance. Specifically, the ASD subgroup with intact structural language ability would verbally mediate planning to a greater degree than the ASD subgroup with impaired structural language ability. This hypothesis is based on the assumption that participants with ASD and structural language impairment would benefit less from using their impaired language skills to regulate behavior on this task, as well as on findings from a language impaired group without ASD using the same experimental paradigm (Larson et al., 2019).

Methods

Participants

The participants in the current study were enrolled in a larger two-year longitudinal project investigating the relationship between language and executive function in school-age children with different language backgrounds: TD monolingual English speakers, TD bilingual English-Spanish speakers, children with ASD, and children with Specific Language Impairment. All children completed a battery of experimental EF tasks with minimal verbal demands and language assessments in both years, while the ToL task was administered only in the second year. All children were recruited from local schools, community centers, and clinics through flyers and website postings. Children with ASD were additionally recruited through a research database at the Waisman Center at the University of Wisconsin-Madison. This database consists of families who have indicated an interest in having their child participate in research studies. All participants had normal (or corrected to normal) vision per parent report and all passed a hearing screening at 20 dB at 1000, 2000, and 4000 Hz.

The current study analyzes experimental data from the second year, and includes a subset of TD and ASD children from the larger study. The present study included 43 TD children (21 males) and 28 children with ASD (24 males) between the ages of 9 and 13 years. The children were distribution matched on age and Nonverbal IQ (*p*'s > .50). Non-verbal intelligence was measured using the Perceptual Reasoning Index of the Wechsler Intelligence Scale for Children, 4th Edition (WISC-IV; Wechsler, 2003). The index consists of scores from three different subtests of the WISC-IV – Block Design, Picture Concepts and Matrix Reasoning. Children in both participant groups spoke English as their native language and exposure to any language other than English was an exclusionary criterion. Exclusionary criteria for TD children included a diagnosis of language impairment, learning disability, psychological/behavioral disorders, neurological impairments, or other developmental disabilities. The TD group did not display behaviors suggesting concerns regarding autism spectrum disorders as judged by the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003), a parent-report screening measure.

All children in the ASD group had previously received a clinical or educational diagnosis within their home communities by a pediatrician, developmental psychologist, school psychologist or an interdisciplinary team. At the time of assessment for this study, the community diagnosis was confirmed by an experienced clinical psychologist using the high-functioning version of the Childhood Autism Rating Scale, Second Edition (CARS-2; Schopler, Van Bourgondien, Wellman, & Love, 2010). A minimum cutoff score of 25 was used as this corresponds to the 10th percentile of CARS-2 scores among individuals with ASD in the standardization sample. Structural language skills for all children were evaluated by administering the Clinical Evaluation of Language Fundamentals – 4th Edition (CELF-4; Semel, Wiig, & Secord, 2003). Scores were obtained for core language, receptive language, and expressive language scales. The language abilities of children with ASD varied considerably. Thus, we subgrouped the full ASD group into structural language normal (LN) and structural language impaired (LI). The LN group (N = 17) had CELF-4 Expressive, Receptive, and Core Language standard scores ≥ 1 SD above the mean and the LI group (N = 11) had CELF-4 Core Language scores > 1 SD below the mean. See Table 1 for participant characteristics.

Procedure

Children were tested on standardized assessments and experimental tasks over the course of 2-3 two-hour visits to the laboratory. Trained graduate and undergraduate research assistants and clinicians administered all the assessments and experimental measures.

Planning measure.—Planning was evaluated by a computerized version of the ToL task. This task was adapted for computerized presentation from the original version developed by Shallice (1982). In this version of the task, children moved beads on pegs in the experimental arrangement to match the target arrangement using the computer mouse. The task was programmed using the ToL software (Tower of London, 2012), which allowed for generating problem sets (trials) depending on the desired number of pegs, beads, or number of moves. We used problems that could be solved in exactly 4 moves which involved three pegs and three differently colored beads. This level of difficulty was chosen so that the task would be challenging enough but not too complex for children in the target age range (Kaller et al., 2008). The trials were normed on adults to ensure that the difficulty levels of the problems were comparable. The final stimulus set consisted of 15 trials that were equivalent in difficulty level where the number of moves ranged from 4 to 4.76 and total time to complete ranged from 7.79s to 13.17s. These fifteen trials were also piloted on three children with ASD within the age range of the study to ensure that they could complete the task.

The 15 trials were randomly assigned to 3 task conditions – no-secondary task, motor suppression secondary task, and articulatory suppression secondary task. In the no-secondary task condition, children completed the Tower task without any dual task. For the motor suppression condition, children were asked to tap their foot on a pedal every time they heard a beep throughout ToL trials. For the articulatory suppression condition, children were instructed to say the word “maybe” out loud every time they heard a beep throughout ToL trials. The beeps consisted of repeated presentations of a simple tone at approximately 750ms intervals (intervals were jittered). Participants were redirected to continue the secondary task if they forgot to do so during the experiment. Each condition included 5 trials, with the same 5 trials presented to all children. We presented conditions in randomized order for each participant, and trial order within each condition was pseudorandomized. Participants had 5 untimed practice trials with feedback. The practice trials did not appear in the experimental conditions and feedback was nonverbal (e.g., pointing to images, demonstration) to the extent possible. We explicitly instructed participants to think about how they would match the experimental arrangement to the target arrangement *before* they initiated their first move.

If a child used more than 20 moves or exceeded 75 seconds from trial onset within a given trial, the experiment proceeded to the next trial. The percent of trials eliminated was 0.02. Outcome measures included: Number of Moves (total moves to complete a trial; accuracy), Planning Time (time taken to initiate the first move), and Execution Time (time taken to complete the trial *after* the first move was initiated). We also recorded and analyzed accuracy on the secondary tasks.

Visual Baseline.—A simple visual task was designed to examine children's processing of visual stimuli. Children were instructed to press the yellow button on a response box as soon as they saw a star on the computer screen. Stimuli consisted of fifty trials of repeated presentations of a solid black star in the middle of a computer screen with a white background. Visual presentations were varied and set to be randomly presented with ISIs of 750ms, 1000ms, 1500ms, 1750ms, and 2000ms. Accuracy and reaction time (RT) data were collected.

Analyses

We analyzed each ToL performance measure separately via linear mixed effects models using the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) in R. Models included the fixed effects of Group (TD vs. ASD), Condition (no-secondary task vs. motor suppression vs. articulatory suppression), Core Language on the CELF-4, and the 3-way interaction between Group, Condition, and Core Language. Random effects included a random by-subject intercept and by-subject slope for Condition. All models included Visual Baseline RT on accurate trials as a covariate as there were significant group differences on this measure ($p < .05$) and the ToL task relies heavily on visual processing.[1]

For the mixed effects models, Group was contrast coded as -0.5 and 0.5 (TD, ASD), Condition was dummy coded initially with no-secondary task as the reference variable and then with motor suppression as the reference variable in order to generate all three condition comparisons: no-secondary task, articulatory suppression secondary task, and motor suppression secondary task. Note that generating all three condition comparisons results in multiple comparisons related to the no-secondary task and motor suppression secondary task conditions; these multiple comparisons were not interpreted in the results (see Table 3 for specific information). Language scores and Visual Baseline RTs were mean-centered, and t-values greater than 1.96 were considered significant at $p < .05$. Per linear model diagnostics, we log transformed each outcome measure. We also eliminated data points from the original sample which exceeded acceptable levels of leverage, regression model fit, and model influence (Judd, McClelland, & Ryan, 2009): Number of Moves n = 3; Planning Time n = 2; Execution Time n = 2 (< 0.003% of trials). As expected, sample sizes for the ASD-LN (N = 17) and ASD-LI (N = 11) subgroups were associated with inadequate power to include

ASD-LI and ASD-LN contrasts in the full mixed-effects models. Thus, we conducted planned follow-up linear regression analyses to explore the relationship between Language and Performance within the TD, ASD, ASD-LN, and ASD-LI groups.

Results

Secondary Task Performance

For the articulatory suppression task accuracy, TD (M = 0.90, SD = 0.11) and ASD (M = 0.92, SD = 0.11) groups did not differ significantly ($p = .551$), and ASD-LN (M = 0.94, SD = 0.07) and ASD-LI (M = 0.89, SD = 0.15) groups did not differ significantly ($p = .326$). For the motor suppression task accuracy, TD (M = 0.72, SD = 0.24) and ASD (M = 0.52, SD = 0.22) groups differed significantly ($b = -0.199$; $t = -3.430$; $R^2 = 0.155$; $p < .01$), indicating that the TD group completed the motor suppression task more accurately than the ASD group. The ASD-LN (M = 0.53, SD = 0.27) and ASD-LI (M = 0.50, SD = 0.13) groups did not differ significantly on motor suppression task accuracy ($p = .693$). Accordingly, we included motor suppression task accuracy as a covariate in statistical models that examined TD-ASD group differences in order to account for potential relationships between secondary task accuracy and ToL performance.

Number of Moves

There was a significant main effect of Condition ($p < .001$) and a significant interaction between Group and Core Language ($p < .05$). When the no-secondary task condition was the reference variable, there were significant effects of both Condition variables – articulatory suppression ($b = 0.267$; $t = 4.596$; $p < .001$) and motor suppression ($b = 0.162$; $t = 3.420$; $p < .001$). Thus, participants used a greater number of moves in the secondary task conditions (articulatory M = 5.64, SD = 3.63; motor M = 5.33, SD = 3.08) than in the no-secondary task condition (M = 4.56, SD = 2.15). When the motor suppression task condition was the reference variable, there was a significant interaction between Core Language and the Condition variable for articulatory suppression ($b = -0.007$; $t = -2.015$; $p < .05$). Participants with relatively better language ability had less of a difference in number of moves used between the articulatory and motor suppression task conditions than participants with relatively poorer language ability. There were no significant effects of Group or other Group interaction terms, and there was no change to results when covarying motor suppression task accuracy (see Table 2 for descriptive data and Table 3 for statistical output).

Follow-up regression analysis indicated that Core Language significantly predicted Moves in the articulatory suppression task condition for the TD group ($b = -0.010$; $t = -3.216$; $R^2 = 0.047$; $p < .01$), but not for the ASD group as a whole ($p = .582$) or when broken down by language status (ASD-LN $p = .280$; ASD-LI $p = .892$). Thus, the participants with relatively better language ability in the TD group used fewer moves in the articulatory suppression task condition than participants in the TD group with relatively poorer language ability. There were no significant effects of Core Language on Moves in the no-secondary or motor suppression task conditions (p's > .05).

Planning Time

There were significant main effects of Condition ($p < .001$) and Core Language ($p < .05$). When the no-secondary task condition was the reference variable, there was a significant effect of the Condition variable for motor suppression ($b = 0.186$; $t = 2.284$; $p < .05$). Participants took longer to plan in the motor suppression task condition (M = 4.98, SD = 2.95) than in the no-secondary task condition (M = 4.71, SD = 3.07). When the motor suppression task condition was the reference variable, there was a significant effect of the Condition variable for articulatory suppression ($b = −0.289$; $t = −4.374$; $p < .001$). Participants took longer to plan in the motor suppression task condition (M = 4.96, SD = 2.95) than in the articulatory suppression task condition (M = 4.14, SD = 2.22). There was also a significant effect of Core Language ($b = 0.008$; $t = 2.339$; $p < .05$). This effect indicates that participants with relatively better language ability took longer to plan in the motor relative to the articulatory suppression conditions and in the motor relative to the no-secondary task conditions than participants with relatively poorer language ability. There were no significant effects of Group or Group interaction terms. When covarying motor suppression task accuracy, the effect of Group became significant ($b = −0.360$; $t = −2.66$; $p < .05$) when the no-secondary task condition was the reference variable. Thus, after accounting for group differences in motor suppression accuracy, the TD group had a greater Planning Time performance detriment (i.e., longer planning times) than the ASD group in the secondary task conditions relative to the no-secondary task condition and in the articulatory suppression task condition relative to the no-secondary task condition. There were no other changes to results when covarying motor suppression task accuracy (see Table 2 for descriptive data, Table 3 for statistical output, and Figure 1).

Follow-up regression analysis indicated that Core Language significantly predicted Planning Time in the no-secondary task condition for the TD group ($b = 0.010$; $t = 2.167$; $R^2 = 0.022$; $p < .05$), but not for the ASD group as a whole ($p = .755$) or when broken down by language status (ASD-LN $p = .153$; ASD-LI $p = .565$). Core Language significantly predicted Planning Time in the articulatory suppression task condition for the TD group ($b = 0.008$; $t = 1.996$; $R^2 = 0.019$; $p < .05$), but not for the ASD group as a whole ($p = .546$). When broken down by language status, Core Language significantly predicted planning time in the ASD-LN group ($b = 0.016$; $t = 2.463$; $R^2 = 0.068$; $p < .05$), but not the ASD-LI group ($p = .757$).

Core Language did not significantly predict Planning Time in the motor suppression task condition for the TD group ($R^2 = 0.018$; $p = 0.054$), although this relationship narrowly missed our significance threshold and its effect size is similar to the effect of Core Language in the articulatory suppression task condition. Core Language significantly predicted Planning time in the motor suppression task condition for the ASD group as a whole ($b = 0.008$; $t = 2.934$; $R^2 = 0.060$; $p < .01$), but not when broken down by language status (ASD-LN $p = .084$; ASD-LI $p = .878$). The significant effect for the ASD group as a whole is likely driven by the ASD-LN group as this effect size ($R^2 = 0.036$) is similar in magnitude to other significant findings (e.g., Core Language as a predictor of Planning Time in the no-secondary task condition for the TD group $R^2 = 0.022$).

Collectively, participants in the TD group with relatively better language took longer to plan across conditions than participants in the TD group with relatively poorer language ability.

Participants in the ASD-LN group showed a similar pattern as the TD group in the articulatory suppression task condition and demonstrated a trend toward a similar pattern as the TD group in the motor suppression task condition. Relative to the ASD-LN group, participants in the ASD-LI group showed patterns less similar to the TD group as their language abilities were not significantly related to Planning Time in any condition (see Figures 1 and 2).

Execution Time

There were significant main effects of Condition ($p < .001$) and Baseline Visual RT ($p < .001$). When the no-secondary task condition was the reference variable, there were significant effects of both Condition variables – articulatory suppression ($b = 0.395$; $t = 4.952$; $p < .001$) and motor suppression ($b = 0.625$; $t = 8.800$; $p < .001$). Thus, participants had longer execution times in the secondary task conditions (articulatory M = 11.81, SD = 10.50; motor M = 14.14, SD = 11.10) than in the no-secondary task condition (M = 8.67, SD = 7.81). There was also a significant effect of Baseline Visual RT ($b = 0.142$; $t = 3.572$; $p < .001$), indicating that participants with relatively longer baseline visual RT took relatively longer to execute trials than participants with relatively shorter baseline visual RT. When the motor suppression task condition was the reference variable, there was a significant effect of Condition for articulatory suppression ($b = -0.229$; $t = -2.445$; $p < .05$). Thus, participants took longer to plan in the motor suppression task condition than in the articulatory suppression task condition. There were no significant effects of Group or other Group interaction terms, and there was no change to results when covarying motor suppression task accuracy (see Table 2 for descriptive data and Table 3 for statistical output).

Follow-up regression analysis indicated that Core Language significantly predicted Execution Time in the articulatory suppression task condition for the TD group ($b = -0.011$; $t = -2.397$; $R^2 = 0.027$; $p < .05$), but not for the ASD group as a whole ($p = .871$) or when broken down by language status (ASD-LN $p = .254$; ASD-LI $p = .685$). Thus, participants with relatively better language ability in the TD group took less time to execute trails in the articulatory suppression task condition than participants in the TD group with relatively poorer language ability. There were no significant effects of Core Language on Execution Time in the no-secondary or motor suppression task conditions (p's > .05).

Discussion

The current study examined the role of verbal mediation in planning on a version of the ToL with minimized verbal demands in children with ASD relative to age- and nonverbal IQ-matched TD peers using a dual-task paradigm. We asked whether groups differ in overall performance and in how language skills are drawn upon to regulate performance on this task. Findings indicated no group difference in accuracy, time spent planning prior to first move, or time spent executing the task after initiating the first move. There were group differences in how language related to performance under certain task demands. The TD group's language skills were associated with all performance measures under articulatory suppression (i.e., disrupted verbal mediation) whereas language skills were associated with planning time in the ASD group under motor suppression (i.e., cognitive load control condition). When we examined patterns in ASD language subgroups, we found no association between language and planning performance in children with ASD and comorbid structural language impairment. Alternatively, the ASD subgroup with structural language ability in the normal range demonstrated an association between language and planning time under articulatory suppression.

Based on planned follow-up analyses, preliminary findings suggest that children with ASD-LI do not verbally mediate planning performance on this task. Children with ASD-LN appear to use verbal mediation to plan prior to executing trials under articulatory suppression – relatively better structural language skills were associated with using more time to plan than relatively poorer structural language skills. It is possible that this pattern reflects difficulty engaging in verbal and nonverbal domain tasks simultaneously given that children with ASD-LN did not appear to draw on verbal mediation at baseline or under motor suppression. In contrast, TD peers appear to use verbal mediation to plan and to execute trials efficiently and accurately under articulatory suppression, as well as to plan prior to initiating their moves in the absence of secondary task demands (i.e., no-secondary task or baseline condition). Relatively better language skills were associated with greater accuracy and shorter execution time under articulatory suppression than relatively poorer language skills in the TD group. Similar to the ASD-LN group, TD children with relatively better language skills used more time to plan than TD children with relatively poorer language skills. Their potential use of verbal mediation, in turn, appears to facilitate their performance speed *and* accuracy even when the secondary task attempts to disrupt verbal mediation. This performance benefit observed in the TD group, however, was not observed in the ASD-LN group. The TD group also demonstrates a trend of using verbal mediation to plan prior to executing trials under motor suppression. These patterns suggest that planning prior to engaging in this relatively nonverbal task is verbally mediated regardless of additional task demands in TD children. Collectively, the role of verbal mediation in planning differs in children with typical development relative to children with ASD depending on structural language status.

The Role of Language in Planning in ASD

Our findings corroborate prior work demonstrating diminished use of verbal mediation to regulate EF behavior in individuals with ASD (Holland & Low, 2010; Joseph et al., 2005; Kercood et al., 2014; Wallace et al., 2009; Whitehouse et al., 2006; Williams et al., 2016). Holland and Low (2010), in particular, is the only prior study to use a dual-task paradigm with a cognitive load control condition (i.e., nonverbal suppression) to examine the role of verbal mediation in planning in children with ASD. They found that performance on their only outcome measure – total execution time (i.e., trial onset to trial completion) – was disrupted by articulatory suppression relative to baseline in the TD group, but not in the ASD group. While their findings broadly align with the current findings, their performance measure conflates time spent planning with total time to complete the trial and they did not measure accuracy.

Other investigations of planning in ASD using a dual-task paradigm without a cognitive load control condition (i.e., only no-secondary task and articulation conditions) have also found diminished use of verbal mediation to regulate performance. Williams et al. (2012) showed greater performance detriment when verbal mediation was disrupted relative to baseline in TD adults relative to adults with ASD matched on age, verbal IQ, performance IQ, and full-scale IQ. Using post-hoc analysis, Wallace et al. (2009) found similar results in children with ASD relative to full-scale IQ-matched TD peers. Neither of the ASD groups in these studies performed less accurately than TD comparison groups. Thus, there is converging evidence that individuals with ASD verbally mediate this complex EF behavior to a lesser degree than cognitive ability-matched TD peers in the absence of an effect on performance accuracy. A key contribution of the current work is demonstrating that these patterns remain evident on a planning task that minimizes the confound of verbally-based task demands.

Another novel contribution of the current work is our examination of planning performance in children with ASD subgrouped by structural language status. The current findings are consistent with other work from our lab showing differences in the relationship between language and EF performance depending on language status (Ellis Weismer et al., 2018; Larson et al., 2019). When examining performance on lower-level nonverbal EF tasks, Ellis Wesimer et al. (2018) found that receptive language predicted performance on an inhibition task in an ASD-LN subgroup and shifting in an ASD-LI subgroup. On our complex EF task, however, children with ASD-LN appear to draw on their language ability to regulate behavior under articulatory suppression whereas children with ASD-LI do not. This discrepancy may relate to differences in task demands (Van Eylen et al., 2015) – tasks in Ellis Wesimer et al. (2018) were less complex than the current planning task. This complexity difference may have reduced the ASD-LI group's ability to draw on impaired language skills to the same degree in the current study as in Ellis Weismer et al. (2018). Children with ASD have more difficulty engaging in complex tasks than simpler tasks, likely due to compounding problems when they must coordinate lower-level EF processes to execute the more complex behavior (Diamond, 2013; Hill, 2004; Joseph et al., 2005; Pellicano, 2010; Pellicano et al., 2017; Unterrainer et al., 2016; Van Eylen et al., 2015). Verbal mediation may represent an additional cognitive process that would draw on their weak language skills to regulate performance on a primarily *nonverbal* complex EF task, thereby adding complexity that is not likely to facilitate successful task completion. Alternatively, the ASD-LN group has intact language skills which may be drawn upon to facilitate performance (Marcovitch & Zelazo, 2009; Zelazo, 2004). It is possible, however, that perseveration or poor inhibitory control on the part of the ASD-LN subgroup in the articulatory suppression condition results in their drawing on verbal mediation given that they are also engaging in a verbal secondary task (Ellis Weismer et al., 2018; Hill, 2004; Liss et al., 2001; Ozonoff et al., 1991; Robinson et al., 2009; Williams et al., 2016). This hypothesis is corroborated by the lack of relationship between language and planning performance in this subgroup at baseline and in the presence of a nonverbal secondary task. It is also corroborated by the lack of facilitative effect of verbal mediation on performance speed or accuracy; an effect which was observed for our TD group.

ASD-LI and ASD-LN group patterns generally align with another study from our lab examining planning in children with Specific Language Impairment (SLI) using the same experimental procedure. Larson et al. (2019) showed that the relationship between language and planning time in a language impaired group differed from a TD group under articulatory suppression. Although we were not able to test whether ASD subgroups differed in the relationship between language and planning performance in the full mixed effects models (i.e., due to sample size limitations), our preliminary evidence shows that children with ASD-LI in the current study did not present with an association between language and planning performance whereas children with ASD-LN did present with this association. In the current study and Larson et al. (2019), children with structural language impairments may have opted to use alternative, potentially nonverbal, strategies to complete the nonverbal planning task without marked performance detriment (Kaller et al., 2008). Taken together, it appears that the facilitative nature of verbal mediation for EF tasks with minimal verbal demands relates to deficit profiles in terms of lower-level EF skills (e.g., perseveration, cognitive flexibility) and language ability (e.g., comorbid language impairment).

Theoretical and Clinical Implications

Although the executive dysfunction account of ASD suggests that characteristic features of ASD, such as perseveration and inflexibility, are secondary to deficits in EF (Hill, 2004; Joseph et al., 2005; Ozonoff et al., 1991), recent work shows that this account does not fully capture the ASD profile (e.g., Leung & Zakzanis, 2014; Pellicano, 2011). Consistent with this more recent work, the current study did not find poorer planning performance in the ASD group relative to the age- and nonverbal IQ- matched TD group. Discrepancies in prior work on EF in ASD may be related to the role of language in EF performance (Holland & Low, 2010; Wallace et al., 2009; Whitehouse et al., 2006) and thus better understood through the HCSM (Marcovitch & Zelazo, 2009; Zelazo, 2004). This model posits an important relationship between language and EF where language in the form of verbal mediation leads to developmental advancement in goal-directed behavior. Accordingly, we would expect performance to be related to language skills across conditions, particularly on a complex EF task that requires coordination of lower-level EF skills (e.g., inhibition and shifting; Diamond, 2013; Zelazo 2004). The current study provides evidence of a facilitative relationship between language and planning performance in typical development when verbal mediation is disrupted, and regardless of secondary task demands for planning time. Aligning with HCSM predictions, language in the form of verbal mediation was particularly important during the time spent planning prior to executing this nonverbal task (i.e., TD children likely engaged in self talk or inner speech to regulate their behavior).

In contrast, there was a relationship between language and planning time in the full ASD group only in the motor suppression condition, potentially driven by the greater similarity in patterns between the ASD-LN and TD group than the ASD-LI and TD group. Indeed, this relationship was similar in magnitude to the TD group for the ASD-LN, but not ASD-LI, group. The ASD-LN group also appears to have verbally mediated planning time in the articulatory suppression condition. These patterns may reflect increased reliance on verbal mediation when the planning task was paired with a secondary task – a greater level of difficulty relative to baseline. Though these findings appear to align with the HCSM, the absence of a relationship between language and performance at baseline (i.e., no secondary task) was not associated with a performance detriment for the ASD-LN group relative to the TD group. Likewise, the use of verbal mediation under articulatory suppression did not appear to facilitate performance speed or accuracy in the ASD-LN group as it did for the TD group. Thus, one alternative interpretation is that the relationship between language and planning performance under articulatory suppression is related to other characteristics of ASD, such as perseveration and inhibitory control. In fact, these are ASD symptoms that the executive dysfunction account of autism explains relatively well (Hill, 2004; Leung & Zakzanis, 2014; Pellicano, 2011), underscoring an elevated likelihood of observing these symptoms in complex EF performance.

Contradicting claims of the HCSM, the ASD-LI group does not appear to draw on their language skills to engage in performance on this complex EF task. It is likely their relatively weak language skills do not support their complex goal-directed behavior, thus they may use alternative, compensatory strategies. For instance, they may use visuospatial strategies to complete this nonverbal planning task (Kaller et al., 2008), similar to what is thought to occur in children with language impairment who do not have ASD (Botting, Psarou, Caplin, & Nevin, 2013; Larson et al., 2019). Taken together, the HCSM is supported by the current work in children developing typically, but potentially not for children with ASD regardless of language status. Rather, it appears that core characteristics of ASD and variance in language ability impose a barrier to the facilitative effects of verbal mediation on EF behavior. It is notable that their performance does not suffer as a consequence of this barrier.

Clinical implications of the current work include considering nonverbal strategy use during goal-directed behavior – it is possible that children with ASD engage in tasks that draw on EF skills differently than TD peers who primarily rely on verbal strategies. It may be beneficial to encourage the use of effective alternative strategies, such as nonverbal strategies, to facilitate functional outcomes in children with ASD. For instance, children with ASD may more successfully complete a novel task (e.g., building a solar system mobile) when general instructions are supplemented with visual depictions of the steps needed to complete the task (e.g., an image demonstrating that a paper clip should be stuck into the planet, then a string should be tied to the paperclip) than with verbal information about the underlying steps (e.g., "tie a string to the paperclip that you have stuck into the top of the planet"). The verbal instructions in this example involve complex syntax which may be challenging for children with ASD, particularly children with ASD-LI. Alternatively, the visual instructions circumvent complex syntax and may lead to a more optimal educational outcome (e.g., identification of all 8 planets in our solar system).

Additionally, it is important to account for variability in language skills within the ASD population as a part of treatment programming. We have shown differences in performance patterns in children with ASD with intact relative to weaker structural language skills, thus highlighting the need for individualized treatment. In contrast to children with ASD-LI, children with ASD-LN may benefit from a balanced approach to strategy use. Specifically, educational goals (e.g., identification of all 8 planets in our solar system) may be better achieved through visual *and* verbal instructions so that they are able to draw on multiple sources of information. Treatment that is individualized according to the language ability of a given child with ASD may also improve outcomes more broadly, such as social functioning. For instance, turn taking goals may be more optimally targeted through verbally-based turn taking (e.g., asking and answering simple questions) for a child with ASD-LN, yet through visually-based turn taking (e.g., playing Connect Four) for a child with ASD-LI. It should be noted that findings from the current study are preliminary and additional work is needed to explore the relative effects of strategy use in functional contexts and treatment individualized per a child with ASD's language level.

Limitations and Future Directions

We note that the group by condition interaction was a null effect in our statistical models. Yet, this finding is not surprising considering that the ASD-LN group showed a pattern more similar to the TD group than the ASD-LI group. Examining performance between conditions with the ASD group as a whole may have confounded the ASD-TD group by condition comparisons. Given the small sample sizes of the ASD language subgroups, however, we were unable to run statistical models with each subgroup compared to the TD group. Future work is indicated to analyze performance patterns in ASD language subgroups, perhaps using larger sample sizes and eligibility criteria more typical of LI group designation (e.g., particular weakness in morphosyntax). Additionally, despite the fact that our version of the ToL task minimized verbal demands, it is largely impossible to remove *all* verbal demands from a given task. Therefore, there may remain a confound in examining the relationship between language and performance, albeit in a relatively minor capacity. Additional examinations of this relationship on complex EF tasks, such as problem solving or reasoning tasks, and other language indices, such as receptive versus expressive measures, would reinforce and extend the current findings. Finally, the motor suppression condition is intended to control for the added cognitive load associated with the articulatory suppression secondary task relative to baseline in the dual-task paradigm, yet the motor and articulatory suppression conditions are not matched in difficulty. Although a lack of equivalence in nonverbal suppression relative to verbal suppression conditions is consistent with prior work (e.g., Gangopadhyay et al., 2018; Holland & Low, 2010; Larson et al., 2019; Lidstone et al., 2012), it remains a limitation that may be addressed in future studies.

Conclusions

The current study asked whether the relationship between language and performance on a planning task with minimal verbal demands differed in children with ASD relative to age- and nonverbal IQ- matched TD peers. Using a dual-task paradigm, we showed that children with typical development verbally mediated performance on this complex EF task under articulatory suppression. They further appeared to draw on verbal mediation to plan prior to initiating performance in the task across conditions. Children with ASD appeared to draw on verbal mediation to plan prior to initiating performance in the task only under motor suppression. Further nuance is evident when breaking the ASD group into structural language impaired and structural language normal subgroups. While children with ASD and structural language ability in the normal range appear to draw on verbal mediation to plan under secondary task demands, these preliminary patterns may be driven by characteristics of their ASD profile (e.g., perseveration, inhibitory control). Alternatively, children with ASD and comorbid structural language impairment did not appear to draw on verbal mediation to regulate performance on this task. It follows that considering compensatory strategies children with ASD may be using to regulate their goal-directed behavior, as well as how these strategies may differ according to structural language status, is critical in clinical and educational settings.

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Figure 1.
Planning Time for the ASD and TD groups in the articulatory suppression condition. *Note*: Data points are jittered; Core Language = Core Language standard scores from the Clinical Evaluation of Language Fundamentals, 4th edition; x-axis represents the range of Core Language scores within each group; y-axis limited to range of 1-20 seconds for visualization; see Table 2 for complete descriptive performance information.

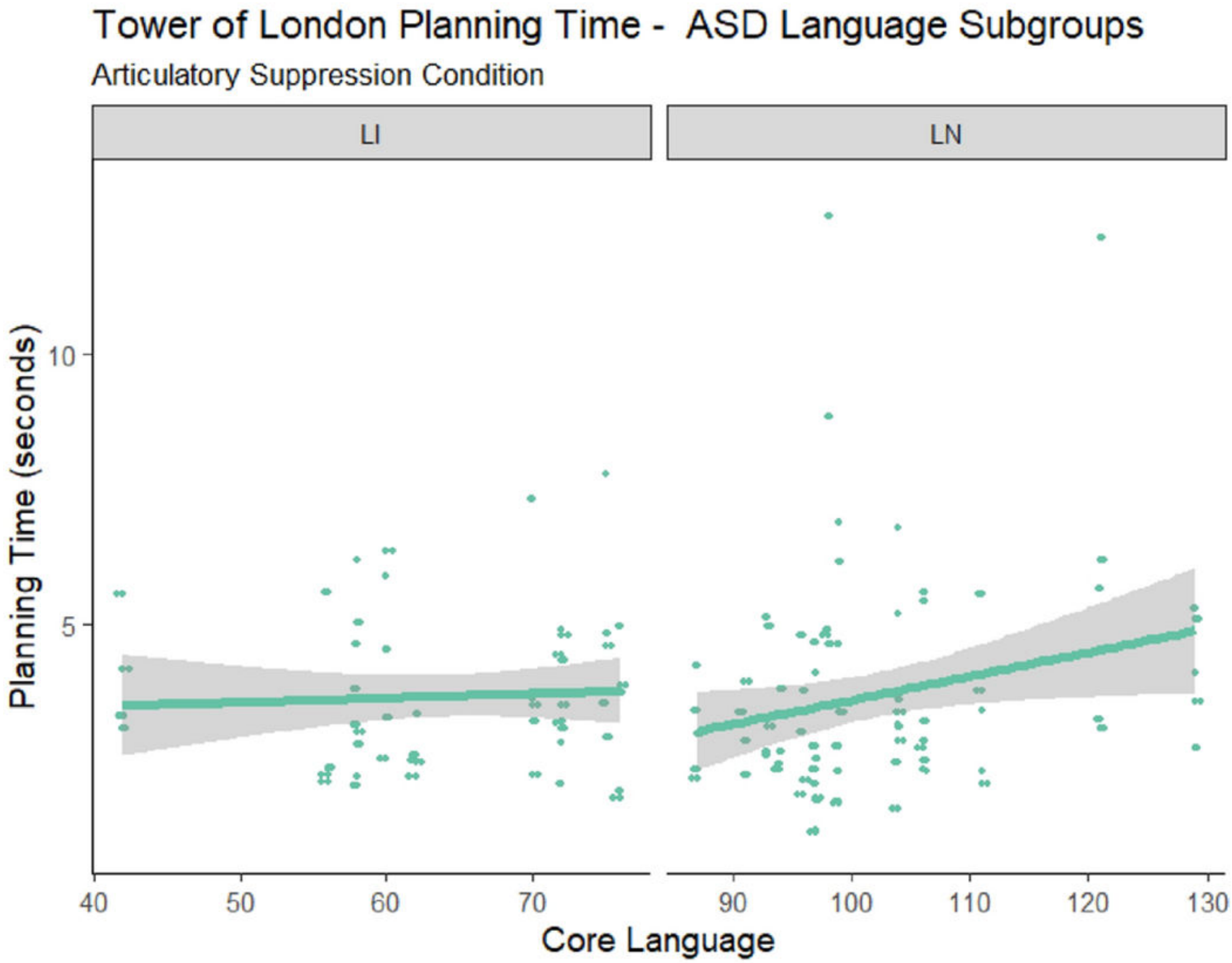

Figure 2.

Planning Time for ASD language subgroups in the articulatory suppression condition. *Note*: Data points are jittered; Core Language = Core Language standard scores from the Clinical Evaluation of Language Fundamentals, 4th edition; x-axis represents the range of Core Language scores within each group; y-axis limited to range of 1-20 seconds for visualization; see Table 2 for complete descriptive performance information.

Table 1.

Participant demographic information and performance on standardized tests, subdivided by group and language status.

Participant Characteristics	TD (*n* = 43)	ASD-All (*n* = 28)	ASD-LN (*n* =17)	ASD-LI />(*n* =11)	*p* values
Age in years					
Mean (SD)	10.6(1.1)	10.8(1.3)	10.9(1.5)	10.6(1.0)	TD<ASD (.51) ASD-LN>ASD-LI (.66)
Range	9.0-13.0	8.9-13.5	9.0-13.5	8.9-12.0	
Maternal education in years (SES)					
Mean (SD)	17.3(3.0)	16.1(3.1)	16.5(3.4)	15.6(2.5)	TD>ASD (.10)
Range	11-24	12-24	12-24	12-19	ASD-LN>ASD-LI (.44)
Nonverbal Cognition (WISC-IV)					
Mean (SD)	109.8(12.2)	108.5(14.2)	113.8(14.6)	100.3(9.0)	TD>ASD (.67)
Range	88-137	86-137	88-137	86-115	ASD-LN>ASD-LI *
Social Comm. (SCQ)					
Mean (SD)	3.8(3.8)	18.9(6.6)	18.3(7.5)	19.7(5.2)	TD<ASD *** ASD-LN<ASD-LI (.58)
Range	0-16	4-35	4-35	15-29	
Core Language (CELF-4)					
Mean (SD)	110.0(12.5)	86.9(21.6)	101.9(10.7)	63.7(10.3)	TD>ASD ***
Range	87-134	42-129	87-129	42-76	ASD-LN>ASD-LI ***
Sex (*count*)	21 M 22 F	24 M 4 F	15 M 2 F	9 M 2 F	TD<ASD *** ASD-LN>ASD-LI (.67)

Note. SES = socioeconomic status; WISC-IV = Wechsler Intelligence Scale for Children, Fourth Edition; SCQ = Social Communication Questionnaire (lower scores indicate better performance); CELF-4 = Clinical Evaluation of Language Fundamentals, Fourth Edition. Standard scores were used for the WISC-IV, CELF-4, and SCQ. ASD LI = autism spectrum disorder, language impairment; scored < 81.25 on CELF-4 Core language standard score (-1.25 SD); ASD LN = autism spectrum disorder, language normal; scored > 81.25 on CELF-4 Core language standard score.

* Group difference at $p < .05$.

** Group difference at $p < .01$.

*** Group difference at $p < .001$

Table 2.

Participants' descriptive data for the Tower of London (ToL) measure, subdivided according to outcome measure, condition, group, and subgroup.

Condition	ToL Measure	TD (*n* =43)	ASD (*n* =28)	ASD-LN (*n* =17)	ASD-LI (*n* =11)
No Secondary Task	Number of Moves				
	Mean (SD)	4.6(2.4)	4.5(1.7)	4.6(2.1)	4.3(0.6)
	Range	4-20	4-20	4-20	4-7
	Planning Time				
	Mean (SD)	5.2(3.5)	4.0(2.2)	3.8(1.9)	4.2(2.5)
	Range	1.6-23.3	1.0-13.3	1.0-12.2	1.5-13.3
	Execution Time				
	Mean (SD)	8.9(8.6)	8.4(6.5)	8.6(8.2)	8.0(2.0)
	Range	3.1-65.2	3.5-70.2	3.5-70.2	4.9-16.5
Articulatory Suppression Secondary Task	Number of Moves				
	Mean (SD)	5.5(3.5)	5.8(3.9)	6.1(4.0)	5.5(3.7)
	Range	4-20	4-20	4-20	4-20
	Planning Time				
	Mean (SD)	4.4(2.4)	3.7(1.8)	3.7(2.0)	3.7(1.4)
	Range	1.2-15.5	1.2-12.6	1.2-12.6	1.8-7.8
	Execution Time				
	Mean (SD)	11.7(9.9)	12.0(11.3)	12.4(11.6)	11.2(11.0)
	Range	3.7-59.8	3.6-61.1	3.6-57.0	4.3-61.1
Motor Suppression Secondary Task	Number of Moves				
	Mean (SD)	5.3(3.1)	5.4(3.1)	5.4(2.7)	5.3(3.6)
	Range	4-20	4-20	4-17	4-20
	Planning Time				
	Mean (SD)	5.3(3.2)	4.5(2.5)	4.8(2.3)	4.0(2.7)
	Range	0.7-19.9	1.5-17.6	1.5-15.2	1.5-17.6
	Execution Time				
	Mean (SD)	14.3(11.4)	13.9(10.7)	14.2(10.6)	13.5(10.9)
	Range	4.1-69.5	5.3-62.35	5.3-52.4	5.3-62.4

Note. TD = typically developing; ASD = Autism Spectrum Disorder; ASD-LN = Autism Spectrum Disorder normal language; ASD-LI = Autism Spectrum Disorder language impairment.

Table 3.

Mixed-effects model results for Number of Moves, Planning Time, and Execution Time performance on the Tower of London.

Outcome Measure	Predictor	*b*	*t*	*p*
Number of Moves				
Reference: NST				
	Group – ASD vs. TD	−0.036	−0.56	0.58
	ConditionNST-AST	0.267	4.57	<.001 ***
	ConditionNST-MST	0.162	3.42	<.001 ***
	Language	−0.000	−0.15	0.88
	Visual RT	0.042	2.00	0.05
	Group *ConditionNST-AST	−0.004	−0.03	0.98
	Group *ConditionNST-MST	0.105	1.10	0.27
	Group *Language	0.003	0.86	0.39
	ConditionNST-AST *Language	−0.004	−1.30	0.20
	ConditionNST-MST *Language	0.003	1.09	0.28
	Group * ConditionNST-AST *Language	0.010	1.59	0.12
	Group * ConditionNST-MST *Language	−0.001	−0.12	0.91
Reference: MST				
	Group – ASD vs. TD	0.068	0.86	0.39
	ConditionMST-AST	0.105	1.66	0.10
	†ConditionMST-NST	−0.162	−3.42	<.001 ***
	Language	0.002	1.19	0.24
	Visual RT	0.042	1.97	0.05
	Group *ConditionMST-AST	−0.108	−0.86	0.40
	†Group *ConditionMST-NST	−0.105	1.10	0.27
	Group *Language	0.002	0.55	0.58
	ConditionMST-AST *Language	−0.007	−2.02	<.05 *
	†ConditionMST-NST *Language	−0.003	−1.09	0.28
	Group * ConditionMST-AST *Language	0.010	1.55	0.13
	†Group * ConditionMST-NST *Language	0.001	0.12	0.91
Planning Time				
Reference: NST				
	Group – ASD vs. TD	−0.282	−1.82	0.07
	ConditionNST-AST	−0.103	−1.45	0.15
	ConditionNST-MST	0.186	2.28	<.05 *
	Language	0.004	1.08	0.29
	Visual RT	0.051	1.08	0.28

Outcome Measure	Predictor	*b*	*t*	*p*
	Group *ConditionNST-AST	0.137	0.96	0.34
	Group *ConditionNST-MST	0.214	1.31	0.19
	Group *Language	−0.008	−1.05	0.30
	ConditionNST-AST *Language	0.001	0.17	0.86
	ConditionNST-MST *Language	0.004	0.90	0.37
	Group * ConditionNST-AST *Language	0.003	0.47	0.64
	Group * ConditionNST-MST *Language	0.010	1.15	0.26
Reference: MST				
	Group – ASD vs. TD	−0.068	−0.51	0.61
	ConditionMST-AST	−0.289	−4.37	<.001 ***
	†ConditionMST-NST	−0.186	−2.28	<.05 *
	Language	0.008	2.34	<.05 *
	Visual RT	0.051	1.08	0.28
	Group *ConditionMST-AST	−0.077	−0.58	0.56
	†Group *ConditionMST-NST	−0.214	−1.31	0.19
	Group *Language	0.001	0.18	0.86
	ConditionMST-AST *Language	−0.003	−0.92	0.36
	†ConditionMST-NST *Language	−0.004	−0.90	0.37
	Group * ConditionMST-AST *Language	−0.006	−0.91	0.37
	†Group * ConditionMST-NST *Language	−0.010	−1.15	0.26
Execution Time				
Reference: NST				
	Group – ASD vs. TD	−0.063	−0.56	0.58
	ConditionNST-AST	0.395	4.95	<.001 ***
	ConditionNST-MST	0.625	8.80	<.001 ***
	Language	−0.001	−0.44	0.66
	Visual RT	0.142	3.57	<.001 ***
	Group *ConditionNST-AST	−0.123	−0.77	0.44
	Group *ConditionNST-MST	0.060	0.42	0.68
	Group *Language	0.005	0.82	0.41
	ConditionNST-AST *Language	−0.003	−0.73	0.47
	ConditionNST-MST *Language	0.004	0.96	0.34
	Group * ConditionNST-AST *Language	0.010	1.19	0.24
	Group * ConditionNST-MST *Language	−0.004	−0.58	0.56

Outcome Measure	Predictor	*b*	*t*	*p*
Reference: MST				
	Group – ASD vs. TD	−0.003	−0.02	0.98
	ConditionMST-AST	−0.229	−2.45	<.05 *
	†ConditionMST-NST	−0.625	−8.80	<.001 ***
	Language	0.002	0.63	0.53
	Visual RT	0.142	3.57	<.001 ***
	Group *ConditionMST-AST	−0.183	−0.98	0.33
	†Group *ConditionMST-NST	−0.060	−0.42	0.68
	Group *Language	0.001	0.07	0.94
	ConditionMST-AST *Language	−0.007	−1.35	0.18
	†ConditionMST-NST *Language	−0.004	−0.96	0.34
	Group * ConditionMST-AST *Language	0.014	1.45	0.15
	†Group * ConditionMST-NST *Language	0.004	0.58	0.56

Note: NST = No-Secondary Task Condition; AST = Articulatory Suppression Secondary Task Condition; MST = Motor Suppression Secondary Task Condition; Reference = reference condition in the statistical model; ASD = Autism Spectrum Disorder; TD = Typically Developing; Language = Core Language standard scores from the Clinical Evaluation of Language Fundamentals, 4th edition; Visual RT = Visual reaction time on baseline task.

† multiple comparison, not interpreted in results;

* $p<.05$;

** $p<.01$;

*** $p<.001$.