DOES LANGUAGE GUIDE BEHAVIOR IN CHILDREN WITH AUTISM?

by

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A dissertation submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Psychology

The University of Utah

August 2013

The University of Utah Graduate School

STATEMENT OF DISSERTATION APPROVAL

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ABSTRACT

It is unknown if children with high-functioning autism (HFA) employ self-directed speech to guide motor sequencing and motor control, or if they can benefit from using self-directed speech when prompted to do so. Participants performed a three-movement sequence across three conditions: Natural Learning, Task-Congruent Verbalization (TCV), and Task-Incongruent Verbalization (TIV). TIV deleteriously impacted performance in the typically-developing group (TD; *n*= 22), and not the HFA group (*n*=21). TCV improved performance in both groups, but to a greater extent in the HFA group. These findings suggest that children with HFA do not initiate self-directed speech spontaneously, but *can* use language to guide behavior when prompted to do so.

This dissertation is dedicated to my husband, Oscar Larson, for his unconditional love and support.

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ACKNOWLEDGMENTS

The author would like to thank the University of Utah’s Autism Research Program and Brigham Young University’s Autism Research Laboratory for help with recruitment of the autism participants. We would also like to thank John Sheehan and Jenny Wilson for their dedication to this research project.

INTRODUCTION

Autism spectrum disorders (ASD) encompass several developmental disorders, all of which are characterized by marked impairment in social and communicative abilities, as well as repetitive behaviors and interests (APA, 2000). Delayed development and/or abnormal use of language is typically seen in children who later develop ASD (Whetherby et al., 2004). Language impairments in ASD are variable, can be seen at very young ages, and include impairments in both verbal and nonverbal forms of communication (Luyester, Kadlec, Carter, & Tager-Flusberg, 2008; Rapin & Dunn, 2003). These language and communicative deficits likely give way to delayed, and in many cases impaired, social interaction in children with autism (Bigler et al., 2007; Pelphrey, Adolphs, & Morris, 2004). From a sociocultural perspective (Vygotsky, 1978), this delay in social interaction is likely to lead to unsuccessful internalization of social speech, which in turn results in delayed or abnormal development of self-directed speech (i.e., private and inner speech[1]), and a subsequent delay in or abnormal emergence of higher-order cognitive functions, including executive and motor functions (i.e., behavioral/action regulation).

Deficits in executive and motor functions are so frequently found in ASD that they are oftentimes described as a central feature of ASD (Hill, 2004; Hilton, Zhang,

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[1] Private speech is conceptualized as self-directive speech spoken quietly (but outwardly) to oneself, while inner speech has been conceptualized as the subsequent process of completely internalizing (i.e., not speaking out loud, rather thinking) private speech (Vygotsky, 1978).

Whilte, Klohr, & Constantino, 2012; Russell, 1997). Compelling evidence supports the existence of impairments in executive function, including deficits in planning, cognitive flexibility, monitoring, working memory, and working memory combined with inhibitory control (Bennetto, Pennington, & Rogers, 1996; Goldberg et al., 2005; Hughes & Russell, 1993; Hughes, Russell, & Robbins, 1994; Joseph, McGrath, & Tager-Flusberg, 2005; Joseph, Steele, Meyer, & Tager-Flusberg, 2005; Ozonoff et al., 2004; Ozonoff & McEvoy, 1994; Ozonoff, Pennington, & Rogers, 1991; Ozonoff & Strayer, 1997; see also Ozonoff & Strayer, 2001; Russell, Jarrold, & Henry, 1996). Similarly, impairments in motor function are well documented in individuals with ASD and include deficits in motor planning and motor sequencing, and in the execution of complex motor skills and gestures (Dewey, 1991; Gidley Larson & Mostofsky, 2006; Hughes, 1996; Leary & Hill, 1996; Minshew, Goldstein, & Siegel, 1997; Mostofsky et al., 2006; Rogers, Bennetto, McEvoy, & Pennington, 1996). Notably, these executive and motor functions are thought to be guided, at least in part, by self-directed speech (Baddeley, 2002, 2003; Baddeley, Chincotta, & Adlam, 2001; R. A. Barkley, 1997; Emerson & Miyake, 2003; Hayes, Gifford, & Ruckstuhl, 1996; Hofmann, Schmeichel, Friese, & Baddeley, 2011; Muller, Jacques, Brocki, & Zelazo, 2009; Smith & Bryson, 2007). Indeed, several lines of research have concluded that the deficits in motor and executive functions seen in ASD may be the result of a failure to spontaneously engage self-directed (i.e., private or inner) speech to regulate behavior and action (Joseph, McGrath, et al., 2005; Joseph, Steele, et al., 2005; Russell, Jarrold, & Hood, 1999).

More specifically, research indicates that individuals with ASD are weak in their ability to spontaneously verbally encode information (i.e., create verbal representations of items or actions), verbalize task demands, and use verbal self-reminding as a strategy to facilitate rehearsal and maintenance of task-specific information within working memory (Joseph, McGrath, et al., 2005; Joseph, Steele, et al., 2005; Russell et al., 1999; Smith & Bryson, 2007). These strategies are all reliant on self-directed speech to enhance working memory and to facilitate goal directed behavior for successful task performance (Joseph, Steele, et al., 2005). Failure to use these strategies results in individuals with ASD being vulnerable to making errors. This is particularly the case when successful performance relies on the ability to flexibly switch between behaviors, plan future actions, inhibit a prepotent response, and/or monitor previous choices and actions (Hughes, 1996; Hughes & Russell, 1993; Joseph, McGrath, et al., 2005; Joseph, Steele, et al., 2005; Russell et al., 1999).

Despite this apparent relationship between impairments in language and impairments in higher-order cognitive processes in individuals with high-functioning autism (HFA), research has only recently begun to focus on inner speech’s relation to cognitive control and working memory in individuals with HFA (Holland & Low, 2010; Wallace, Silvers, Martin, & Kenworthy, 2009; Whitehouse, Maybery, & Durkin, 2006; Williams, Happe, & Jarrold, 2008). Those studies that examined cognitive control in children with HFA compared to typically-developing (TD) children used a dual-task design that is known to interfere with inner speech. More specifically, participants completed a task under a control condition and an articulatory suppression condition; that is, they completed the task while verbalizing a task-irrelevant word (e.g., Monday) (Holland & Low, 2010; Wallace et al., 2009; Whitehouse et al., 2006). It was consistently found that the TD children performed more poorly when verbalizing the task-irrelevant word, while the children with HFA showed no effect of the task-irrelevant verbalization. These findings suggest that while cognitive control is supported by the use of inner speech in TD children, this is not the case for children with HFA. Instead, it appears that children with HFA do not employ inner speech to support cognitive control, and thereby to guide their behavior. This impairment in inner speech has been posited to contribute to the executive dysfunction commonly seen in children with HFA (Wallace et al., 2009).

In contrast to studies examining cognitive control, those examining working memory yielded inconsistent findings: one study reported inner speech impairment in children with HFA (Whitehouse et al., 2006) and the other reported no impairment (Williams et al., 2008). In order to clarify the inconsistencies within the literature, two recent studies have reanalyzed portions of the aforementioned data (Lidstone, Fernyhough, Meins, & Whitehouse, 2009; Williams & Jarrold, 2010). They found that the children with HFA who demonstrated higher verbal abilities were more likely to employ inner speech to support working memory and exhibited a pattern of performance similar to the TD children. In contrast, those children with weaker verbal abilities did not rely on inner speech to support working memory, and instead relied on a different strategy to perform the task, albeit not as well as those using verbal strategies (Lidstone et al., 2009; Williams & Jarrold, 2010).

Although the current literature suggests that the ability to use inner speech to guide behavior is impaired in children with HFA, several aspects of the prior studies limit this interpretation. First, inner speech use has only been examined in tasks of cognitive control and working memory, *not* overt motor behavior. Thus, it is hard to discern if the impairment in inner speech use is specific to cognitive control/processes, or if it extends to more basic aspects of overt motor behavior. This is important given that inner speech is theorized to not only guide higher-order cognitive function, but also to guide and control behavior and basic motor output (Helstrup, 2000; Luria, 1959, 1961; Luria & Homskaya, 1964; Tinsley & Waters, 1982; Vygotsky, 1962; Woodin & Heil, 1996). Second, as evidenced by prior research, it is clear that children with HFA do not spontaneously employ inner speech; however, it is unknown if they can benefit from using self-directed speech to guide behavior when prompted to do so. In fact Russell et al. (1999) posed a question asking whether “children with autism are less likely [than typically-developing children] to benefit from overt speech [i.e., private speech] in motor tasks” (p. 111). To our knowledge, this has yet to be explored.

In order to address these limitations of prior research, the present study characterized the extent to which inner speech guides overt motor behavior in children with and without HFA using a task that is based on the Push-Turn-Taptap task, which is a well-validated motor learning task (Kraybill & Suchy, 2011; Kraybill, Thorgusen, & Suchy, 2013; Suchy, Derbidge, & Cope, 2005; Suchy, Eastvold, Whittaker, & Strassberg, 2007; Suchy & Kraybill, 2007; Suchy, Kraybill, & Franchow, 2011; Suchy, Kraybill, & Gidley Larson, 2009). The aims of the study were (a) to replicate and extend prior research by examining the effect of task-irrelevant verbalization on *overt motor behavior* as opposed to cognitive control; and (b) to determine if children with HFA can use language to guide behavior when prompted to do so, even if they do not initiate private or inner speech spontaneously. To examine these aims, participants were asked to perform a sequence of hand movements across three conditions: (1) Natural Learning Condition (i.e., no manipulation, essentially learning the movements as they naturally would, using their own self-initiated strategy), (2) Task-Congruent Verbalization Condition (i.e., performing the learned sequence of movements while making a task-congruent verbalization), and (3) Task-Incongruent Verbalization Condition (i.e., performing the learned sequence of movements while making a task-incongruent verbalization).

We hypothesized that (a) motor performance (both with respect to execution of the overall sequence, and with respect to control of discrete single movements) would be deleteriously affected by task-incongruent verbalization in the TD group, but not the HFA group; and (b) that in children with HFA, motor performance would benefit from a language strategy if one is provided externally.

METHODS

Participants

A total of 43 (21 high-functioning autism (HFA) and 22 typically-developing (TD)) male[2] children participated in this study. HFA participants were recruited from the University of Utah's Autism Research Database and Brigham Young University's Autism Research Laboratory. TD participants were recruited through the posting and distributing of flyers at schools, community centers, organizations (e.g., Boy Scouts), libraries, pediatrician's offices, and word of mouth. Participants were between the ages of 10 and 16 years. Per parent report, all participants were right handed, spoke English as their first or primary language, had a birth weight greater than 2000 grams, had no history of seizures or traumatic brain injury, no known perinatal drug exposure, and no current illicit drug use. Additionally, all participants had a word reading grade equivalent score of at least 3rd grade, as measured by the Word Reading subtest on Wechsler Individual Achievement Test- Second Edition (WAIT-II; Wechsler, 2002).

Consistent with the gold standard in autism diagnosis, all children in the HFA group met DSM-IV algorithm criteria for autism (APA, 2000), confirmed using the Autism Diagnostic Observation Schedule – Generic (ADOS; Lord et al., 2000).

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[2] This study included only males since research indicates that autism is more likely to occur in boys than in girls with a 4:1 ratio (APA, 2000). Also, the database that we recruited from was consistent with this ratio and few girls met our eligibility criteria. As such, only males participated in this study.

Additionally, with the exception of 6 participants[3], all HFA participants also met algorithm criteria for autism using the Autism Diagnostic Interview – Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994).

TD children were eligible for the study if they met the following criteria, per parent report: no presence of ASD in any immediate family members (i.e., siblings, parents), free from diagnosis of attention deficit/hyperactivity disorder (ADHD) or reading disability, and a T-score < 55 on the Social Responsiveness Scales (SRS) Total Score (Constantino, 2003). The SRS was completed by a parent and assesses motivational, expressive, receptive, and cognitive aspects of behavior associated with autism. It has been found that SRS Total Scores greater than 60 are highly associated with a diagnosis of ASD (Constantino et al., 2003).

This study was approved by the University of Utah's Institutional Review Board. Written consent was obtained from a parent/guardian and written assent was obtained from all participating children.

Design, Materials, and Measures

Using a computerized motor sequence learning task, we employed a mixed 3 (condition, within subjects) X 2 (diagnosis, between subjects) design, with motor performances used as dependent variables. More specifically, participants were trained to perform a complex motor sequence with their dominant (i.e., right) hand; once the sequence was learned, participants performed the task across three conditions, with each

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[3] These 6 participants were not administered the ADI-R as part of a previous research protocol.

condition varying by the amount and the type of language used (i.e., natural learning vs. task-congruent/task-incongruent verbalizations).

Motor sequence learning task. Motor sequence learning was assessed using a task based on the Push-Turn-TapTap (PTT) task from the Behavioral Dyscontrol Scale-Electronic Version (BDS-EV; Kraybill & Suchy, 2011; Kraybill et al., 2013; Suchy, Derbridge, & Cope, 2005; Suchy et al., 2007; Suchy & Kraybill, 2007; Suchy et al., 2011). Participants sat in front of a computer screen and performed a complex motor sequence using the BDS-EV response console (see Figure 1), and unlike the traditional PTT task, the sequence was performed across three Verbalization Conditions. The motor sequence consisted of three hand movements performed in the following order: Push (push joystick forward), Turn (turn joystick in a clock-wise direction), TapTap (tap the white dome two times).

Brief training phase. To learn the correct sequence of movements and so as to avoid confounding the experimental manipulation with the learning curve associated with repeated execution of the task, participants first completed a Brief Training Phase.

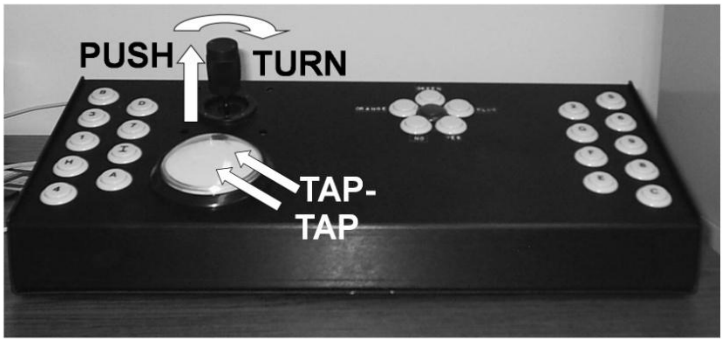


Figure 1. *Behavioral Dyscontrol Scale – Electronic Version Response Console (Suchy, Derbridge, & Cope, 2005).* Participants were asked to perform a sequence of three hand movements (e.g., “push,” “turn,” “taptap,”) using the BDS-EV Response Console.

Training consisted of nine trials in which participants were instructed to perform the movements along with pictures displayed on the computer screen. The length of this training period was based on our prior work that has shown that participants achieve the asymptote of their performance before the completion of the ninth trial; in other words, no statistically significant improvements in performance were evident after the ninth trial. At the end of the ninth trial, the pictures disappeared from the screen and the participants were asked to continue to perform the movements on their own. The disappearance of the pictures denotes the start of the Natural Learning Condition.

Verbalization conditions. To examine the effect of types of verbalization on motor performance, there were three Verbalization Conditions: (1) Natural Learning (NL) Condition, (2) Task-Congruent Verbalization (TCV) Condition, and (3) Task-Incongruent Verbalization (TIV) Condition. As a reminder, based on our past research, we expected no additional effect of practice at this point, as the learning curve would have reached an asymptote. For each Verbalization Condition, participants completed 21 performance trials of the same motor sequence learned during the Brief Training Phase.

The NL Condition was administered first and served as a baseline of natural performance. It was not affected by experimental manipulation, and participants were *not* provided the verbal labels of the sequence nor were they asked to use any specific strategy. In other words, during the NL Condition, participants were simply instructed to perform the sequence of movements as best and as quickly as they could.

The other two conditions (i.e., TCV and TIV) varied based on the words the participants were instructed to verbalize. During the TCV Condition, participants were instructed to verbalize a word that was congruent to their action. For example, participants said “push” as they made the push movement. In contrast, during the TIV Condition, participants were instructed to verbalize a word that was incongruent to their action. For example, participants said “push” as they made the tap-tap movement. Each of these two conditions (i.e., TCV and TIV) was preceded by three practice trials to ensure understanding of the new task demands (see Figure 2).

During the three practice trials that preceded the TCV and TIV Conditions, the movements were pictorially displayed on the screen in the correct order along with the words that the participants were expected to say out loud. After the three practice trials, the pictures of the movements and words disappeared. Participants were instructed to continue to perform the movements on their own, while saying out loud the words presented during the practice trials. In all conditions, if participants made an error, an audible beep sounded, and a picture of the correct movement was displayed on the screen; otherwise the screen remained blank. Participants received a short 1-2 minute break between each Verbalization Condition (see Figure 2).

Careful consideration was given to the order in which the three conditions should occur. While we considered counterbalancing, it became clear that changing the order of the three conditions could change the construct being measured. In particular, the NL Condition must be given first as we wanted to see participant’s natural approach to the task prior to any manipulation. Similarly, the TCV Condition had to be given prior to the TIV Condition because we wanted to ensure that all participants were using the same action words, and that those words were paired with the congruent movements. For this reason, the same order was maintained for all participants. Because our hypotheses all involved simultaneous examination of both within and between subjects comparisons

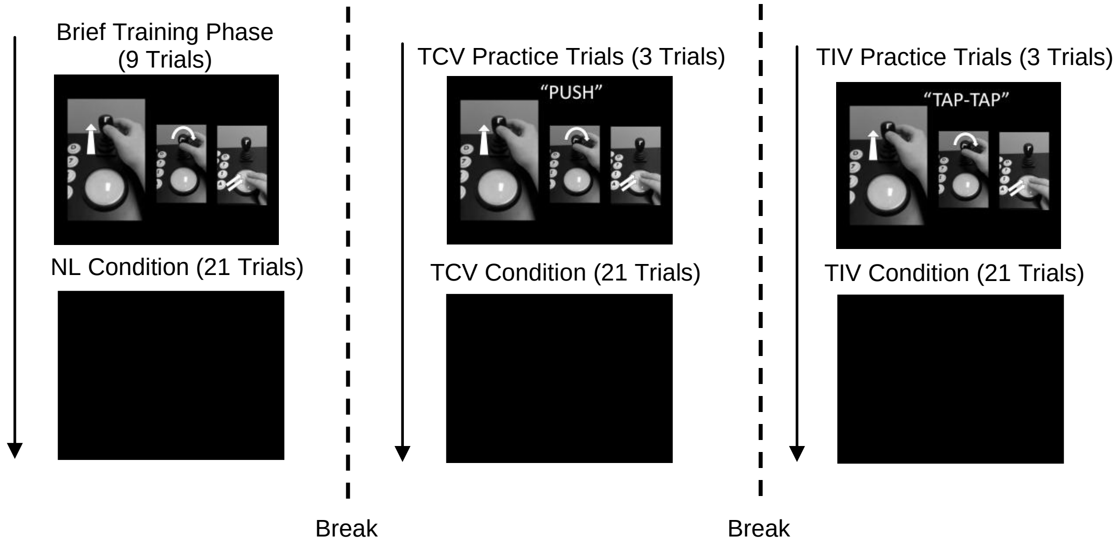


Figure 2. *Motor Sequence Learning Task.* Examples of the motor sequence learning task and screens presented during the Verbalization Conditions. The motor sequence learning task consisted of a Brief Training Phase that consisted of nine sequences in which the sequence order was display pictorially. At the end of the ninth sequence, the pictures disappeared and the NL Condition began. The TCV and TIV Conditions followed, each being preceded by 3 practice sequences during which pictures and the appropriate verbal labels were displayed. After the practice trials, the screen went blank and participants continued to perform the task. The NL, TCV, and TIV Conditions each consisted of 21 sequences. The NL and TCV Conditions were each followed by a 1-2 minute break.

(and the interactions between the two), the effect of order will essentially be controlled for by the presence of the control group.

Motor sequence learning task variables. The motor sequence learning task yielded four motor performance variables. Two of these variables reflected speed and accuracy across the performance of the entire sequence (i.e., sequencing ability), and the other two variables reflected speed and accuracy of executing a single discrete movement within the sequence (i.e., motor control). Recently, data from our lab examining healthy college-students showed that language facilitated, to *varying degrees*, each of these discreet components of motor performance. Given that these well-established discreet components of motor performance were shown to be differentially impacted by verbalization, the current study used the same four components of motor performance as dependent variables, using a modified methodology of Suchy and Kraybill (2007).

Sequencing ability (speed and accuracy). Sequencing Ability is directly impacted by how well the sequence has been consolidated after it has been learned. *Sequencing Performance Speed* refers to the total amount of time required for completion of the entire sequence, measured in ms. Sequencing Performance Speed was calculated for all movement sequences regardless of errors made. *Sequencing Accuracy* refers to the ability to maintain the task-appropriate mental process or response over time. *Sequencing Accuracy* was assessed by counting the total number of errors after the task has been learned, that is after the practice trials. The computer program flagged incorrect movements, initiation of incorrect movements, and poorly executed movements (e.g., turning the joystick in the wrong direction, not turning the joystick enough, etc.) as errors. It should be noted that errors made on the tap-tap movement (e.g., conducting a single tap or a triple tap instead of the double tap) were excluded from this total given that those errors are considered to reflect Motor Control Accuracy rather than Sequencing Accuracy.

Motor control (speed and accuracy). Motor Control refers to correct execution of discrete movements (Suchy & Kraybill, 2007; Whiting, Vogt, & Vereijken, 1992; Willingham, 1998). The motor sequence learning task is comprised of three different movements, one of which is a double tap, or tap-tap, movement. This single discrete movement is regularly executed by most people (i.e., double click on a computer) on a daily basis, and the inability to perform this movement smoothly and correctly reflects poor motor control (Suchy & Kraybill, 2007). Evidence suggests that perseverations in this discrete movement are associated with early declines in motor control (Belanger et al., 2005; Grigsby & Kaye, 1996; Grigsby, Kaye, & Robbins, 1992; Suchy & Kraybill, 2007). Therefore, Motor Control was operationalized as the speed and accuracy of the tap-tap movement. For the *Motor Control Speed* variable, the latency time between the first tap and the second tap was recorded for each trial/sequence only if the movement was performed accurately. For the *Motor Control Accuracy* variable, errors involving the tap-tap movement (e.g., triple-tap, single-tap) were counted.

Brief cognitive assessment. To generate an estimate of intellectual functioning, all participants completed four subtests from the Wechsler Intelligence Scales for Children-IV (WISC; Wechsler, 2003): Vocabulary, Similarities, Block Design, and Matrix Reasoning. From these subtests, a prorated Verbal Comprehension Index (VCI) and Perceptual Reasoning Index (PRI) were obtained.

Procedures

To determine initial eligibility, a 2-5 minute phone screen was conducted with the parent prior to enrollment in the study. Participants who were determined to be eligible were scheduled to come to the Neuropsychology Laboratory for testing. As noted above, all of the children participating in the HFA group were recruited through Utah Autism Database and the BYU Autism Research Laboratory. All participants had received the ADOS and ADI-R through participation in previous research studies, with the exception of 6 participants who had not received the ADI-R as part of a previous research protocol. All participants gave permission for those scores to be released and used in the current research study. All participants first completed the Basic Word Reading subtest from the WIAT-II. Next, participants completed the motor sequence learning task (i.e., Brief

Training Phase and the three Verbalization Conditions). Lastly, following a short break, participants were given a brief cognitive assessment. While the child was being tested, the parent was asked to fill out the SRS. In addition to the scheduled breaks between Verbalization Conditions, participants were given breaks as needed throughout the testing sessions. The entire session lasted approximately 2 hours.

RESULTS

Demographic and Psychological Characteristics of the Sample

Since a full-scale IQ was not obtained, participants were compared across both the Perceptual Reasoning Index (PRI) and the Verbal Comprehension Index (VCI). Independent sample *t*-tests revealed no significant differences between groups on age, [$t = 1.73$, $df = 41$, $p = .092$; Cohen's $d = .48$]; VCI, [$t = 1.27$, $df = 41$, $p = .211$; Cohen's $d = .39$]; or PRI, [$t = .758$, $df = 41$, $p = .453$; Cohen's $d = .23$]. The sample was predominantly Caucasian (91% Caucasian, 5% Hispanic/Latino, 2% Asian/Pacific Islander, and 2% Biracial). As expected, there were significant group differences on the SRS Total Score [$t = 12.6$, $df = 40$, $p < .001$; Cohen's $d = 3.8$], with the HFA group having significantly more impairment in social responsiveness. Demographic variables for the two groups are described in Table 1.

Preliminary Analyses

To ensure that there was no additional learning of the task after the Brief Training Phase, preliminary analyses were conducted examining performance on the motor performance variables across the 21 performance trials contained within the NL Condition (which occurred immediately following the Brief Training Phase). For the purpose of analyses, the 21 Performance Trials were grouped into seven Performance Blocks, with each Block reflecting either the mean performance values (i.e., Motor Control Speed and Sequence Performance Speed) or the sum of performance errors (i.e.,

Table 1.

Demographic Characteristics of the HFA and TD Groups

	HFA **(*n*= 21)**		**TD** **(*n*=22)**	
	M	*SD*	*M*	*SD*
Age	14.3	1.8	13.4	1.5
VCI	103.9	19.9	110.4	13.1
PRI	103.5	17.0	100.0	13.3
WIAT-II	101.2	16.4	107.4	12.5
SRS-T	77.1**	12.3	42.2**	3.9
ADI-Social[a]	20.2	4.7	--	--
ADI-Comm[a]	15.3	4.7	--	--
ADOS-Total	13.2	3.1	--	--

Note. VCI = Verbal Comprehension Index, Standard Score; PRI = Perceptual Reasoning Index, Standard Score; SRS-T = Social Responsiveness Scale – Total, T-score; ADI-Social = Autism Diagnostic Interview-Revised Social Interaction scale, the cutoff for autism is 10; ADI-Comm = Autism Diagnostic Interview-Revised Communication and Language scale, the cutoff for autism is 8; ADOS-Total = Autism Diagnostic Observation Schedule Communication and Social Total score, cutoff for ASD is 7 and for autism is 12.

[a] ADI scores are only for 15 of the 21 participants.

** group difference of $p < .01$

Sequence Accuracy and Motor Control Accuracy) of three contiguous sequence trials. Repeated measures ANOVA across the seven Performance Blocks indicated no significant main effects of Block or Group X Block interactions for *any* of the motor performance variables, in all cases $p > .05$. Together, these findings suggest no additional learning curve following the Brief Training Phase for either group.

Additionally, to determine whether children with HFA differed from TD children in their performance at baseline (i.e., the NL condition), and/or whether any differences were limited to a particular aspect of motor output, we conducted a repeated measures ANOVA, using assessment Mode (speed vs. accuracy) as one within-subjects factor, Motor Ability (sequencing vs. control) as another within-subjects factor, and Group as a between-subjects factor. For this analysis, we converted all dependent variables to z-scores to allow comparison across speed and accuracy and across sequencing and control variables. The results yielded a significant interaction between Group and Mode [$F(1, 41) = 7.55$; $p = .009$, $\eta_p^2 = .156$], such that TD children performed faster overall than HFA children [$t = 2.29$, $df = 41$, $p = .027$; Cohen's d= .70], while HFA children performed somewhat (nonsignificantly) more accurately overall than TD children [$t = 1.32$, $df = 41$, $p = .195$; Cohen's d= .40].

Principal Analyses

Given that there was no learning curve following the Brief Training Phase, for the purpose of statistical analyses, the 21 Performance Trials within each Condition were collapsed into a single observation. This single observation reflected either mean performance values (i.e., Motor Control Speed and Sequence Performance Speed) or the sum of performance errors (i.e., Sequence Accuracy and Motor Control Accuracy) of the 21 contiguous sequence trials. Across all analyses, these values were used as dependent variables, Condition (i.e., NL vs. TCV vs. TIV) was used as the within-subjects factor, and Group (i.e., HFA vs. TD) was used as the between-subjects factor. Statistics of interest included (a) a significant interaction between Condition and Group, which would reflect that the language manipulation had a differential effect on performance across the two Groups, (b) a main effect of Group, which would indicate an effect of diagnosis on performance, and (c) a main effect of Condition, which would indicate an effect of language manipulation on performance irrespective of diagnosis.

Hypothesis A: Natural learning (NL) vs. task-incongruent verbalization (TIV). Repeated measures ANOVA was used to examine the hypothesis that motor performance (both the execution of the overall sequence and the control of discrete single movements) would be deleteriously affected by task-incongruent verbalization in the TD group, but not the HFA group. Consistent with this hypothesis, as well as previous research, analyses indicated the groups were differentially affected by the TIV, such that the TIV Condition had negative impact on virtually all aspects of performance for the TD group, but had generally *no* negative impact for the HFA group. This differential impact of TIV was consistently present for speed, but less so for performance accuracy. Analyses for the motor variables are described below.

Sequencing ability (speed and accuracy). Repeated measures ANOVA of *Sequence Performance Speed* time across the single observation revealed a significant Condition X Group interaction [$F(1, 41) = 8.46$; $p = .006$, $\eta_p^2 = .171$]. Consistent with our hypothesis, paired *t*-tests indicated that the TD group was deleteriously affected by the TIV as compared to the NL [$t = 3.46$, $df = 21$, $p = .002$; Cohen's d= .74], while the HFA group exhibited no effect of TIV [$t = .633$, $df = 20$, $p = .534$; Cohen's d= .13]. There was a significant main effect of Condition [$F(1, 41) = 4.09$; $p = .050$, $\eta_p^2 = .091$], although this effect was clearly driven by the TD group. No significant main effect of group was found [$F(1, 41) = 1.86$; $p = .180$, $\eta_p^2 = .043$]. See Figure 3a.

Repeated measures ANOVA of *Sequence Accuracy* across the single observation yielded a significant main effect of Condition [$F(1, 41) = 12.24$; $p = .001$, $\eta_p^2=.230$], and a main effect of Group [$F(1, 41) = 4.15$; $p = .048$, $\eta_p^2=.092$]. These findings show that both groups were negatively impacted by the TIV, as evidenced by poorer accuracy in the

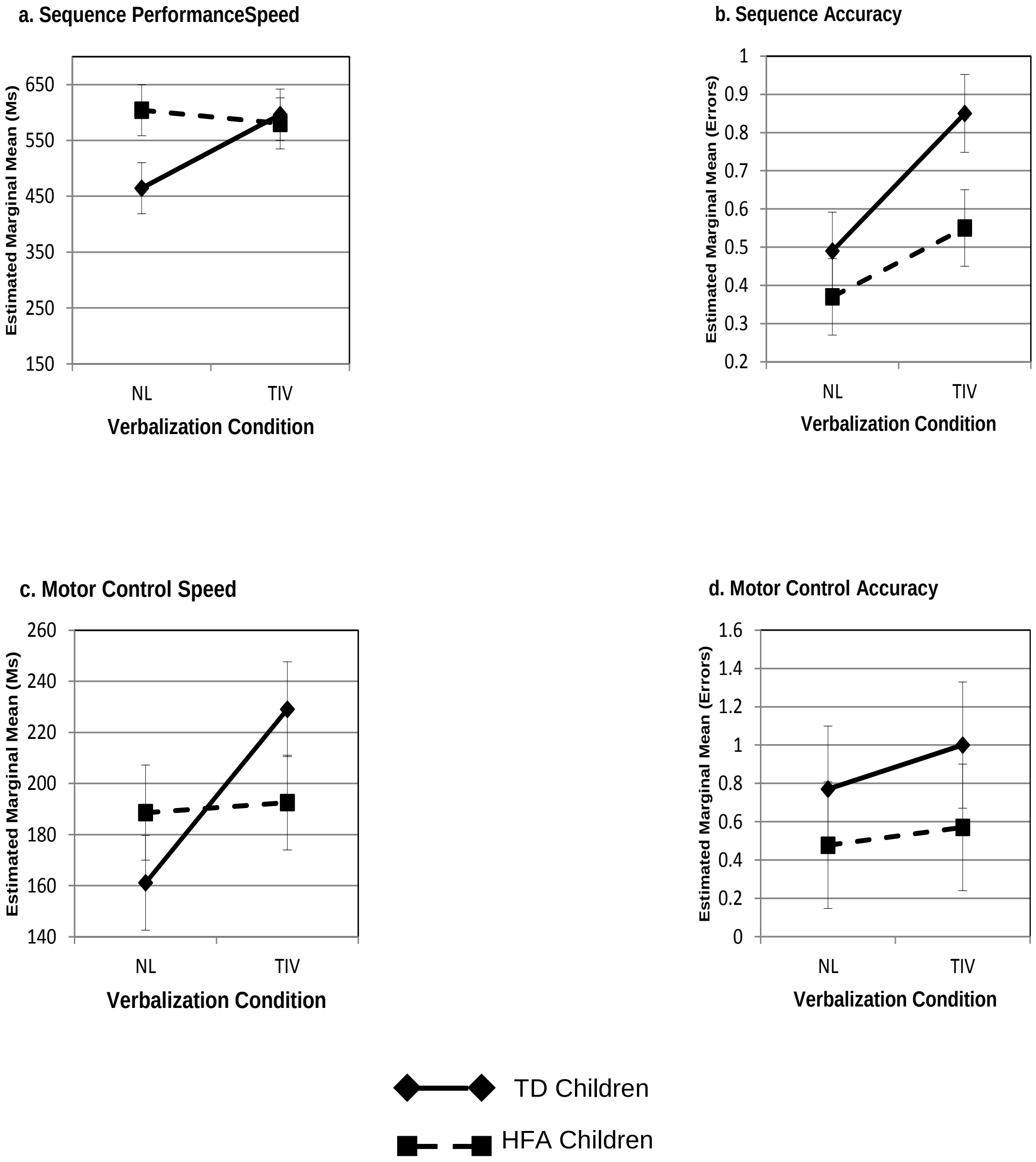
TIV Condition as compared to the NL Condition. The findings also indicate that overall the HFA group had better Sequence Accuracy than the TD group. There was no significant Condition X Group interaction [$F(1, 41) = 1.46$; $p = .234$, $\eta_p^2 = .034$]. See Figure 3b.

Motor control (speed and accuracy). Repeated measures ANOVA of the *Motor Control Speed* (i.e., speed of the tap-tap movement) across the single observation revealed a significant Condition X Group interaction [$F(1, 41) = 5.55$; $p = .023$, $\eta_p^2 = .119$], indicating that the verbal manipulations affected the two groups differently. As hypothesized, follow-up paired *t*-tests revealed that the HFA group showed no decrement in performance across conditions [$t = .197$, $df = 20$, $p = .846$; Cohen's $d = .04$], while the TD group was deleteriously affected by the TIV [$t = 3.65$, $df = 21$, $p = .001$; Cohen's $d = .78$]. There was also a significant main effect of Condition [$F(1, 41) = 6.99$; $p = .012$, $\eta_p^2 = .146$]; however, this effect was driven by the pattern of performance displayed by the TD group across blocks and not the HFA group. There were no significant main effects of Group [$F(1, 41) = .061$; $p = .806$, $\eta_p^2 = .001$]. See Figure 3c.

In contrast, repeated measures ANOVA of *Motor Control Accuracy* of the tap-tap movement indicated no significant main effects or interaction (all p values $>.10$). This suggests that verbalization paired with action serves as a useful tool to facilitate smooth and rapid execution of discreet movements, but not necessarily the accuracy of the movements. See Figure 3d.

Hypothesis B: Natural learning (NL) vs. task-congruent verbalization (TCV). Repeated measures ANOVA was used to examine the hypothesis that in children with HFA, motor performance (both the execution of the overall sequence and the control

Figure 3. *Performance across the NL and TIV Conditions.* For the purpose of statistical analyses, the 21 sequence trials within the NL and TIV Conditions were grouped into one single observation reflecting either mean performance values or the sum of performance errors of the 21 contiguous sequence trials. Error bars for all graphs represent the 95% confidence interval. **(a)** Line graph showing mean Sequence Performance Speed (in ms) across Verbalization Condition. Analyses revealed a significant Condition X Group interaction (p = .006). Follow-up analyses indicated that only the TD group was deleteriously affected by the TIV Condition as compared to the NL Condition (p = .002). There was also a significant main effect of Condition, (p = .050). **(b)** Line graph showing mean Sequence Accuracy errors across Verbalization Condition. Analyses yielded a significant main effect of Condition, (p = .001), and of Group, (p = .048). **(c)** Line graph showing mean Motor Control Speed latencies (in ms) across Verbalization Conditions. Analyses yielded a Condition X Group interaction (p = .023). Follow-up analyses indicated that only the TD group was deleteriously affected by the TIV (p = .001). There was also a significant main effect of Condition (p = .012), driven by the pattern of performance displayed by the TD group across blocks and not the HFA group. **(d)** Line graph showing mean Motor Control Accuracy errors across Verbalization Condition. Analyses revealed a no significant main effects (all p values >.10).


a. Sequence PerformanceSpeed
Estimated Marginal Mean (Ms)
650
550
450
350
250
150
NL
TIV
Verbalization Condition
b. Sequence Accuracy
Estimated Marginal Mean (Errors)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
NL
TIV
Verbalization Condition
c. Motor Control Speed
Estimated Marginal Mean (Ms)
260
240
220
200
180
160
140
NL
TIV
Verbalization Condition
d. Motor Control Accuracy
Estimated Marginal Mean (Errors)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
NL
TIV
Verbalization Condition
TD Children
HFA Children

of discrete single movements) would benefit from a language strategy if one is provided externally. Consistent with expectation, our findings indicate that both speed and accuracy of motor sequencing benefits from TCV. In contrast, motor control does not appear to be significantly impacted. Analyses for the motor variables are described below.

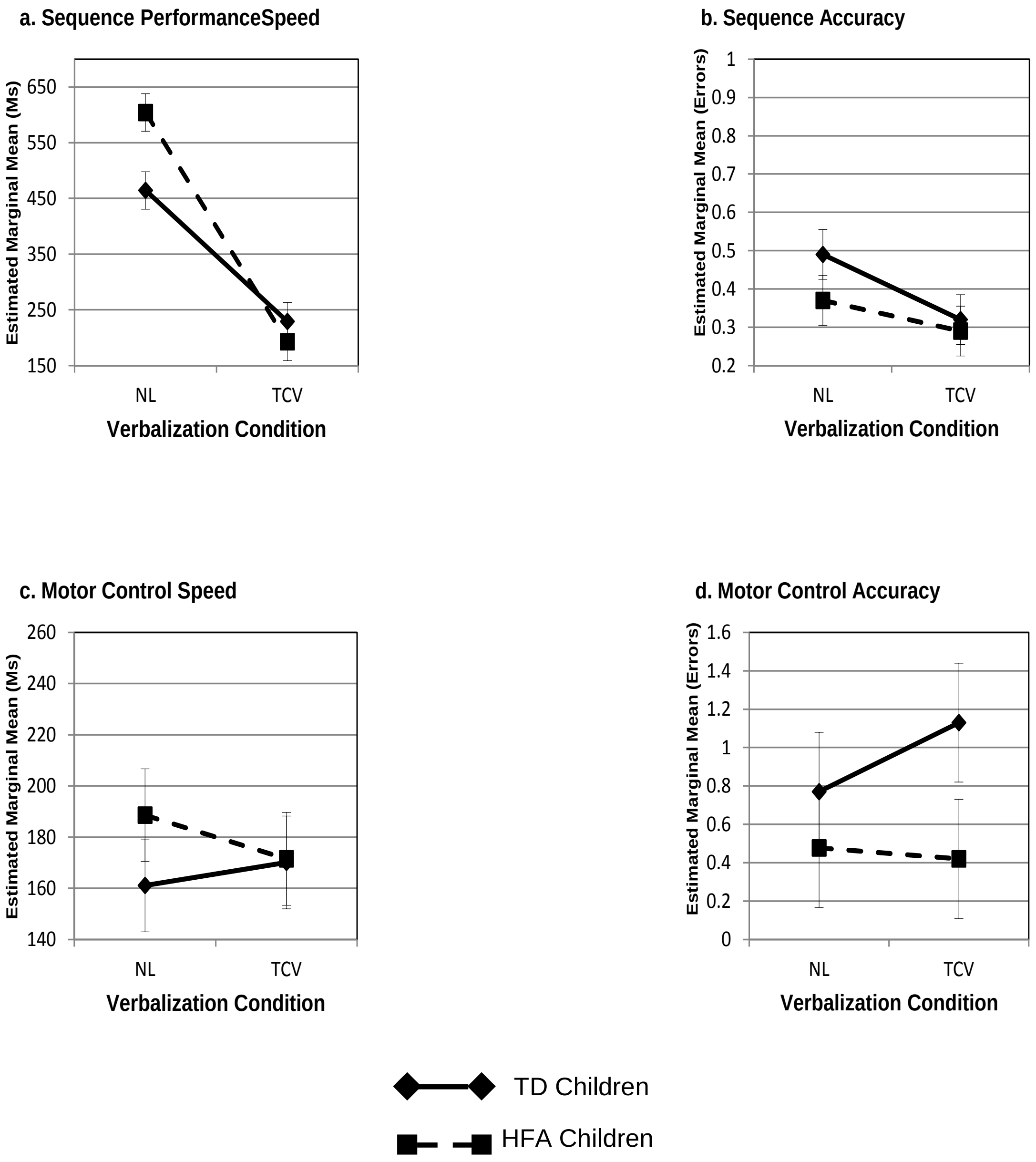
Sequencing ability (speed and accuracy). Repeated measures ANOVA of *Sequence Performance Speed* time across single observation revealed a significant main effect of Condition [$F(1, 41) = 172.52$; $p \leq .001$, $\eta_p^2 = .808$], with both groups benefitting from the use of congruent verbalization, as evidenced by faster Performance Speed in the TCV Condition relative to the NL Condition. However, there was also a significant Condition X Group interaction [$F(1, 41) = 12.81$; $p = .001$, $\eta_p^2 = .238$]. Consistent with our hypothesis, while both groups showed improvement, the congruent verbalizations appeared to have improved the speed of performance for the HFA group to a greater degree, such that their performance became on par with the TD group. Specifically, follow-up independent sample *t*-tests indicated that whereas the HFA group exhibited slower Sequence Performance Speed compared to the TD group during the NL Condition [$t = 2.68$, $df = 41$, $p = .011$; Cohen's $d = .81$], there were no group differences during the TCV Condition [$t = 1.36$, $df = 41$, $p = .181$; Cohen's $d = .42$]. See Figure 4a.

Repeated measures ANOVA of *Sequence Accuracy* across the single observation yielded a significant main effect of Condition [$F(1, 41) = 4.148$; $p = .048$, $\eta_p^2=.092$], with both groups showing improved accuracy during the TCV Condition as compared to the NL Condition. There was no main effect of Group [$F(1, 41) = 1.242$; $p = .272$, $\eta_p^2=.029$], and no significant Condition X Group interaction [$F(1, 41) = .454$; $p = .504$, $\eta_p^2= .011$].

See Figure 4b.

Motor control (speed and accuracy). In contrast to the analyses examined for hypothesis A, testing of hypothesis B yielded null results for *Motor Control Speed* and *Accuracy* of the tap-tap movement, with no significant main effects or interactions (all *p* values >.10). See Figures 4c and 4d.

Figure 4. *Performance across the NL and TCV Conditions.* For the purpose of statistical analyses, the 21 sequence trials within the NL and TCV Conditions were grouped into one single observation reflecting either mean performance values or the sum of performance errors of the 21 contiguous sequence trials. Error bars for all graphs represent the 95% confidence interval. **(a)** Line graph showing mean Sequence Performance Speed (in ms) across Verbalization Condition. Analyses revealed a significant main effect of Condition ($p \leq .001$). There was also a significant Condition X Group interaction ($p = .001$). Follow-up analyses indicated that HFA group exhibited slower Sequence Performance Speed compared to the TD group during the NL Condition ($p = .011$), but no group differences were found during the TCV Condition ($p = .181$). **(b)** Line graph showing mean Sequence Accuracy errors across Verbalization Condition. Analyses yielded a significant main effect of Condition ($p = .048$). There was no significant main effect of Group ($p = .272$) and no significant interaction ($p = .504$). **(c & d)** Line graphs showing mean Motor Control Speed latencies (in ms) and Motor Control Accuracy errors across Verbalization Condition, respectively. Analyses revealed a no significant main effects or interactions (all p values >.10).


a. Sequence PerformanceSpeed
Estimated Marginal Mean (Ms)
650
550
450
350
250
150
NL
TCV
Verbalization Condition
b. Sequence Accuracy
Estimated Marginal Mean (Errors)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
NL
TCV
Verbalization Condition
c. Motor Control Speed
Estimated Marginal Mean (Ms)
260
240
220
200
180
160
140
NL
TCV
Verbalization Condition
d. Motor Control Accuracy
Estimated Marginal Mean (Errors)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
NL
TCV
Verbalization Condition
TD Children
HFA Children

DISCUSSION

The current study investigated the degree to which language guides motor behavior in children with and without autism by examining performance of a complex motor sequence across three conditions that differed by the amount and type of language used (i.e., natural learning vs. task-congruent or task-incongruent verbalizations). The key findings of the present study are that (a) task-incongruent verbalization does not impact motor performance in the children with HFA, but deleteriously impacts performance in TD children; (b) motor performance in children with HFA can benefit, to some degree, from being provided a verbal strategy to help guide motor behavior; and (c) that language appears to be more important for guiding motor sequencing than it is for guiding a single movement.

Consistent with our first hypothesis, children with HFA do not appear to spontaneously use inner speech to guide motor behavior, whereas TD children do. This was evidenced by a greater cost of task-incongruent verbalization (i.e., interfering speech) for the TD children than for the children with HFA. For nearly all aspects of motor performance, the degree of interference from the TIV for the TD children reduced their performance to comparable, or worse, levels of performance as those observed in the HFA children. Notably, we found that while verbal mediation does play a clear role in guiding speeded performance for TD children (i.e., Motor Control Speed and Sequence Performance Speed), it plays less of a role in guiding the accuracy of their sequencing or discrete movements (i.e., Motor Control Accuracy and Sequence Accuracy). More specifically, although performance accuracy for both groups appeared to be impacted to some degree by the TIV, error bars in the graphs (see Figures 3b and 3d) suggest that the TD group had a greater deleterious effect than did the HFA group, primarily with respect to accurate motor sequencing. Consistent with previous reports, it does appear that children with HFA do not spontaneously employ inner speech in the service of overt motor behavior (Holland & Low, 2010; Wallace et al., 2009; Whitehouse et al., 2006). Interestingly, however, a failure to use language does not appear to have a deleterious impact on accuracy of their performance. Although this was a somewhat unexpected finding, it is consistent with prior research that found that while individuals with ASD took longer than TD controls to prepare and execute goal-directed aiming movements, there were no differences in accuracy between the groups (Glazebrook, Elliott, & Lyons, 2006). Together, this suggests that individuals with ASD may have developed a strategy in which they move slowly to ensure more accurate motor performance.

Our second hypothesis was also supported. Both the HFA and TD children benefitted from the use of a verbal strategy, as evidenced by improvement in performance across most motor variables when task-congruent verbalizations (i.e., verbal strategy) were provided. However, while both groups did benefit, it was only on Sequence Performance Speed that there was a significant interaction, in which Performance Speed in children with HFA benefitted from the verbal strategy to a much greater degree than did that of the TD children. That said, the examination of the graphs and error bars suggests that even though formal examination of the Motor Control Speed variable did not yield statistically significant results, a larger sample may have yielded a significant interaction in the expected direction (see Figure 4c). Additionally, across the speeded variables (i.e., Sequence Performance Speed and Motor Control Speed) the children with HFA were able to perform comparably fast to the TD children with the help of an externally provided verbal strategy. These findings suggest that children with HFA *can* use language to guide behavior when prompted to do so, even if they do not initiate private or inner speech spontaneously.

A not entirely unexpected finding was that language appears to be more important for guiding motor sequencing than it was for guiding a single movement. Research indicates that the execution of discrete movements is less complex than the execution of motor sequences. More specifically, neuroimaging studies have found that the execution of simple discrete movements relies on fewer brain regions than does the execution of a motor sequence. Motor sequencing recruits brain regions associated with motor control, as well as executive control, namely those areas associated with the storage of motor sequences within working memory (Catalan, Honda, Weeks, Cohen, & Hallett, 1998). Given the role that inner speech plays in maintaining working memory (Baddeley, 1983, 2003; Baddeley et al., 2001) and the greater reliance on verbal mediation as task complexity increases (Sokolov, 1968/1972, 1969), it is not surprising that language is recruited more for guiding motor sequencing than it is for guiding a single discrete movement.

To our knowledge, this is the first study to explicitly examine the role that language plays in guiding motor behavior, both at the level of motor sequencing, and at the level of discrete movements imbedded within a sequence in children with and without ASD. Results from the current study extend prior research and indicate that the lack of the ability to spontaneously recruit inner speech in children with ASD is pervasive across functional domains, including motor behavior, and not limited only to higher-order cognitive functions (Holland & Low, 2010; Wallace et al., 2009; Whitehouse et al., 2006). This is important given that inner speech has been theorized to guide higher-order cognitive function, as well as to guide and control behavior and basic motor output (Luria, 1959, 1961; Luria & Homskaya, 1964; Tinsley & Waters, 1982; Vygotsky, 1962). More specifically, inner speech is postulated to be maintained “on-line” within working memory and to trigger the retrieval and reactivation of past experience and previously generated rules to problem-solve, plan future actions, and regulate goal-directed behavior (Baddeley, 2000, 2002; Baddeley et al., 2001; Baddeley & Hitch, 1974; R. A. Barkley, 2001; Emerson & Miyake, 2003; Hayes et al., 1996; Muller et al., 2009; Zelazo & Frye, 1997). As such, the failure to engage or adequately utilize inner speech has been hypothesized to contribute, at least in part, to the motor and executive dysfunction frequently documented in children with ASD (Holland & Low, 2010; Joseph, McGrath, et al., 2005; Joseph, Steele, et al., 2005; Russell et al., 1999; Wallace et al., 2009; Whitehouse et al., 2006).

Consistent with this notion of motor and executive dysfunction in children with ASD, results from the current study revealed that baseline performance (i.e., NL Condition) of the speeded variables, in particular the Sequence Performance Speed variable, was poorer in the HFA group as compared to the TD group. This is consistent with several prior studies utilizing dual-task methodology, which also found that children with HFA had poorer baseline performances on some tasks of cognitive control when compared to TD children (Holland & Low, 2010; Wallace et al., 2009; Whitehouse et al., 2006). Together, this supports the findings that children with HFA perform more poorly than TD children on some motor and executive tasks under normal conditions.

Although there is evidence from the current study and the extant literature to support deficits in motor and executive functioning in children with ASD, findings from the current study also indicate that children with ASD are, at times, still capable of performing the task demands *without* utilizing inner speech. Specifically, in the current study comparable baseline performance (i.e., NL Condition) across groups was noted in terms of the Accuracy variables, as well as Motor Control Speed. Consistent with reports from other dual-task studies, the HFA group managed to perform at their baseline levels even when under an interference condition (i.e., TIV Condition and articulatory suppression condition) (Holland & Low, 2010; Wallace et al., 2009; Whitehouse et al., 2006). This suggests that they were able to maintain a complex motor sequence, switch back and forth, and/or plan without enlisting inner speech to guide their behavior. The fact that children with HFA appear to be able to, at least at times, flexibly switch their behavior and control an action without using inner speech to guide their behavior begs the question: do children with autism use a mechanism other than language to guide behavior?

There is a growing body of literature to suggest that children with ASD rely more on visuospatial representations instead of verbal representations (i.e., inner speech) to guide their behavior (Holland & Low, 2010; Joseph, Steele, et al., 2005; Whitehouse et al., 2006). This finding is consistent with literature indicating that children with autism have intact, and often superior, visuospatial abilities, and that they have been found to “think” in pictures rather than words (Caron, Mottron, Rainville, & Chouinard, 2004;

Edgin & Pennington, 2005; Grandin, 1995; Hurlburt, Happe, & Frith, 1994; Kana, Keller, Cherkassky, Minshew, & Just, 2006; Mitchell & Ropar, 2004; Silk et al., 2006). This is also supported by neuroimaging studies which found that children with ASD rely on visuospatial networks (i.e., occipito-parietal and ventral temporal regions), rather than on language networks (i.e., frontal and temporal regions), even when visual representation is difficult and stimuli have low image-ability (e.g., justice), and when information is obviously verbal and easily verbally encoded (e.g., letters) (Kana et al., 2006; Koshino et al., 2005; Manjaly et al., 2007; Sayhoun, Belliveau, Soulieres, Schwatrz, & Mody, 2010). Similarly, studies of white matter integrity indicated that children with autism have greater connectivity between posterior regions and weaker connectivity from posterior to frontal regions (Sayhoun et al., 2010).

Based on these findings, it is likely that in the current study, the children with HFA employed visuospatial mediation, as opposed to inner speech, to guide their motor performance. While it is important to recognize the use of visuospatial mediation as an alternative mechanism to guide behavior, it is also important to recognize the limitations of this strategy. In fact, evidence suggests that visuospatial representations may be able to support tasks that are overlearned, familiar, or simple, but that they are unable to adequately support and flexibly guide behavior in a complex, dynamic, and demanding environment as effectively as verbal representations (Carruthers, 2002; Emerson & Miyake, 2003; Helstrup, 2000; Joseph, Steele, et al., 2005; Koshino et al., 2005; Mottron, Morasse, & Belleville, 2001). The failure of visuospatial mediation to withstand the demands and challenges of more complex environments, and the inability to employ verbal mediation is what likely contributes, at least in part, to the widespread report of motor and executive deficits in children with ASD (Bennetto et al., 1996; Goldberg et al., 2005; Hughes & Russell, 1993; Hughes et al., 1994; Joseph, McGrath, et al., 2005; Joseph, Steele, et al., 2005; Ozonoff et al., 2004; Ozonoff & McEvoy, 1994; Ozonoff et al., 1991; Ozonoff & Strayer, 1997).

Given the limitations of the use of visuospatial mediation and the fact that verbal mediation is likely to be a more effective tool to help guide behavior in novel, complex, and challenging environments, it is important to determine if verbal mediation can be a potential target for intervention in children with ASD (Russell et al., 1999; Wallace et al., 2009). Our study is the first to suggest that children with HFA can use language to guide some aspects of motor behavior when prompted to do so, even if they do not initiate self-directed speech spontaneously. More specifically, we found that when task-congruent verbalizations were provided, motor performance across both groups improved to some degree, particularly for the speeded variables. Further, on several of the motor variables, performance in the HFA group became comparable to that of the TD group. While our findings are somewhat limited and in need of replication, they suggest that even though verbal mediation is not the default strategy for children with ASD, teaching self-directive speech as a declarative strategy may help to improve the motor and executive deficits commonly seen in ASD, particularly in regards to performance speed and for actions that require correct sequencing of movements.

Notably, our findings are consistent with the only other study to date that has examined outwardly spoken self-directed speech (i.e., private speech) in children with ASD. Winsler and colleagues (2007) found that children with ASD performed better on tasks of executive functioning when they employed private speech, and made more errors when they remained silent. While Winsler et al. (2007) examined naturally occurring private speech, we examined prompted or scripted private speech. Our results were similar in that when private speech was used, regardless of whether it was initiated on its own or prompted, performance in children with HFA benefitted. Consistent with the conclusion of Winsler et al. (2007), it appears that children with HFA do benefit from the use of private speech; however, there is either a delay or an abnormal transition of private to inner speech resulting in them not being able to spontaneously employ verbal mediation to guide and regulate their behavior.

Our findings, however, are constrained by several factors. Our study has a modest sample size and replication of our findings is needed. Additionally, it may be that the findings from the current study, as well as those from the other studies using articulatory suppression, may have limited application because the tasks used were not overly complex, enabling children with HFA to effectively utilize a nonverbal strategy to guide their motor sequencing. Thus, future research should consider using more complex tasks (i.e., those with more difficult trials or more lengthy motor sequences). This is important because it has been shown that as a task increases in complexity, there is greater reliance on verbal mediation (Sokolov, 1968/1972, 1969). In fact, the notion that verbal strategy is more useful for more complex tasks is also consistent with our findings, in that there clearly was a benefit of verbalization on the complex task of sequencing multiple movements, but no benefit for execution of a single movement. Thus, it may be that as a task increases in complexity, children with HFA would benefit to an even greater degree from an externally provided verbal strategy because their visuospatial strategy is not able to support task demands.

Additionally, our study is limited by the inclusion of only children with high-functioning autism. While the use of a high-functioning sample was needed to ensure that the task demands were understood, it is possible that children with lower functional capacities have a different pattern of performance and may rely more heavily on nonverbal strategies to guide behavior. As a result, they may be more amenable to intervention strengthening self-directed speech.

Lastly, our study compared performance across diagnostic groups (i.e., HFA vs. TD). Recent research suggests that variables, other than autism diagnosis, predict the ability to use verbal mediation to guide behavior. In fact, several studies have recently re-examined previously published data and report that multiple factors contribute to the impairment in the ability to employ inner speech in children with HFA. More specifically, one study found that a cognitive profile with greater nonverbal abilities as compared to verbal abilities was associated with greater impairment in inner speech during a task of cognitive control (Lidstone et al., 2009). Another study found that verbal abilities predicted inner speech use above and beyond cognitive profile in a working memory task (Williams & Jarrold, 2010). Thus, future research may want to examine the predictors of inner speech in overt motor behavior, as they may be different from those of cognitive control and working memory. Additionally, since the sociocultural perspective (Vygotsky, 1978) theorizes that both delayed or abnormal language *and* social interaction leads to unsuccessful internalization of social speech which in turn results in delayed or abnormal development of self-directed speech, research should begin to explore if variables such as social abilities or autism severity predict the degree to which language guides behavior in children with ASD.

In conclusion, the findings from the current study extend prior research in several ways: (1) by demonstrating that children with HFA do not employ inner speech to guide motor behavior, (2) that language appears to be more important for guiding motor sequencing than it is for guiding a single movement, and (3) that speed of motor performance in children with HFA benefits when a verbal strategy is provided to help guide motor behavior. Since language is posited to be a more flexible and powerful tool to effectively guide behavior, particularly in complex or demanding environments, it is imperative that self-directed speech be intact and accessible as a strategy to guide behavior. Given that inner speech is less accessible in children with ASD, our findings support the development of intervention strategies aimed at strengthening and encouraging the use of verbal mediation to guide behavior, particularly motor sequencing, in children with HFA.

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