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Research article

Complexity and Autism Spectrum Disorder: Exploring Hysteresis in A Grasping Task

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Abstract: In the current paper, we explored the presence of hysteresis in Autism Spectrum Disorder (ASD). Hysteresis is a complexity flag, known to shed light on the dynamics of nonlinear systems. We chose a task that elicits hysteresis in typical development and carried it out with children with ASD. Specifically, children were asked to lift cubes that got increasingly bigger and then smaller (or vice versa). Smaller cubes could be lifted with one hand, whereas bigger cubes required two hands to be lifted. Thus, the change in cube size forced participants to switch their grasping patterns (from one hand to two vs. from two hands to one). The dependent variable was the transition point at which the switch in lifting patterns happened. Results show hysteresis for ASD, to the same degree found for typically developing children (Experiment 1). However, when a social component was added to the task (children had to hand the cubes to the experimenter), a clear difference was found between diagnostic groups (Experiment 2): While typically developing children still demonstrated hysteresis in their grasping, ASD participants no longer did so. It appears that the coordination dynamics of a motor task changed when children with ASD were asked to interact with the experimenter. We discuss the extent to which the analysis of coordination dynamics provides a unique window into understanding ASD.

Keywords: atypical development; children; coordination dynamics; social coordination; perseveration

1. Introduction

Complexity science makes the radical claim that behavior is the result of massive interactions across all parts of the system. This claim implies that behavior cannot be reduced to a sequential causal chain of effects, but instead resides in the interaction of various aspects of the system. Thus, when behavior deviates from what is considered normal, complexity science advocates for a focus on the nature of the interactions, rather than a focus on an underlying causal factor. In the current paper, we apply these ideas of interaction-dominant processes to Autism Spectrum Disorder (ASD), a disorder characterized by persistent problems in social interactions and communication across a wide range of activities [1]. To what extent can ASD be captured by an aberration in how individual parts of the system interact with each other?

1.1. Interaction-dominant processes as a basis of behavior

For systems as varied as a school of fish, an ant colony, a group of fireflies, or an ecosystem, the intrinsic nature of components, agents, or processes cannot capture the behavior of the whole system: There is no miniature version of the school of fish inside an individual fish. And there is no miniature version of an ant hill inside an individual ant. Instead, it is the interaction between the agents and component processes and the interdependence of how they change in relation to each other that defines the macroscopic behavior of the system [2–5].

The main strength of a systems approach is that it can explain nonlinear changes in behavior—changes in behavior that do not follow a corresponding change in the outside context [6]. Nonlinear behavior in humans is ubiquitous: A child does not learn incrementally, one experience at a time; nor does the child forget experiences incrementally, one memory at a time. Instead, learning and forgetting speeds up at times and slows down other times, even to the point of being stagnant. The same way bodies show a growth spurt, behavioral changes can be on a fast track too, for example when children experience a vocabulary spurt [7] or when adults seemingly stumble on a solution after having given up trying (the so-called "Eureka Effect"). And vice versa, learning sometimes stalls, for example when children overgeneralize words incorrectly [8], or when they apply an ineffective problem-solving strategy repeatedly [9].

Cause-effect theories of human behavior cannot account for nonlinear behavior. After all, why would an outside factor affect the system sometimes, but not always? In contrast, theories that emphasize interactions among component anticipate nonlinear behavior. If separate parts of the system can change each other, then behavior no longer has to change in one-to-one correspondence with changes in outside factors. Put differently, because there are circular causal relations between components and the whole, a sequential progression from cause to effect gets interrupted. In fact, nonlinear systems can display holistic behaviors that are far removed from the initial conditions that gave rise to the system. Given that the holistic behavior of the system changes the behavior of individual components, the system cannot be fully understood by isolating micro-scale components. To what extent could interaction-dominant processes be relevant to our understanding of ASD?

The research on ASD is marred by a striking difficulty to isolate its causes, despite extensive research efforts on numerous fronts [10,11]. The problem starts with lacking a uniform characterization of behavior: Even though the APA has settled on a definition, experts in the field debate it heavily. It seems that ASD is characterized by high variability, both within an individual, as well as between individuals [12]. Such diversity is an important indication that ASD is the result of interdependent processes. If ASD is indeed the outcome of interdependent processes, then the pressure of finding a uniform essence of ASD is off. Thus, it is worth explicitly testing whether interdependence could be the source of ASD.

In the case of interaction-dominant processes, we would expect that behavioral manifestations of the disorder show an aberration in an interaction, more so than in a single unit. Indeed, the main characteristics of ASD—abnormal social interaction and communication—are relational aspects: They are emergent in the interaction with others [13]. Even at the level of an individual child, outside of a social or communicative context, the aberrations are relational [14]. In the current study, we explore yet another aspect of interaction-dominant systems, namely that a change in the context affects the interaction, more so than a single unit. We looked specifically at hysteresis as a flag of interaction-based behavior.

1.2. Hysteresis: A complexity flag

Hysteresis is a system's dependency on its immediate history, the changes in an effect lagging behind the changes in its cause over time [15]. Despite continued changes in an outside factor, the system's behavior does not change continuously. Instead, it shows a lingering of the same behavior even as the outside factor prescribes a different behavior. A good example is the rate at which a metal can be magnetized versus demagnetized [16]: While magnetization happens monotonically, demagnetization shows a delay compared to changes in the magnetic field. Within the realm of human behavior, hysteresis has been demonstrated in perception of speech categorization [17], in the perception of affordances [18], and in grasping tasks [19–21].

Looking at grasping tasks more specifically, individuals are typically asked to pick up a series of objects of different sizes. Some of these objects are small enough that they can be picked up with one hand, and others require two hands to be lifted. The crucial manipulation is the order in which objects are presented: Objects are either small at first and then gradually increase in size. Or they are large at first and then gradually decrease in size. In the first case, when objects are small at first, a transition from one-handed to two-handed grasping must occur. In the second case, when objects are large at first, a transition from two-handed to one-handed grasping must occur. For typically developing individuals, the transition point usually occurs at larger object sizes when objects are presented in an ascending order as compared to a descending order, meaning that TD individuals demonstrate hysteresis on this task [22,23]. Using the grasping task, the current study explores hysteresis in ASD. In Experiment 1, a group of children with ASD were asked to lift one cube after another and place each one on a platform. The crucial manipulation was cube size. The dependent variable was whether a cube was lifted with one hand or two. Specifically, we looked at the transition point at which children switch lifting pattern: from one hand to two, or from two hands to one. An age-matched control group of typically developing children (TD) was included to compare the transition points across diagnostic groups. Experiment 2 used the same motor task of lifting cubes of various sizes, but now a social component was added. Rather than placing the cubes on a platform, the task was to hand the cubes to the experimenter who was sitting across the participant. An age-match control group of typically developing children was again included.

All aspects of this study were approved by an Institutional Review Board. Parents or legal guardians of the participants signed a written informed consent, and children provided verbal assent.

2. Experiment 1

To what extent do children diagnosed with ASD show hysteresis in a motor task, namely when asked to lift cubes that change in size incrementally? Participants were recruited as part of a larger research project. The data reported here comes from only a subset of the tasks children were asked to complete.

2.1. Method

2.1.1. Participants

The sample consisted of 41 children who met diagnostic criteria for ASD (35 males, 6 females) and 42 typically developing children (31 males, 11 females), group-matched based on chronological age. For children with ASD, the mean age was 8:6 years (*SD* = 1:5 years) with a range of 6:2 to 10:9 years. For TD children, the mean age was 8:2 years (*SD* = 1:6 years), with a range of 6:3 to 10:11 years. There was no difference in age ($p = 0.2$) between the two groups of children. Each participant was randomly assigned to one of two presentation orders (ascending phase first or descending phase first).

Diagnoses of ASD were confirmed by trained clinicians who administered the Autism Diagnostic Observation Schedule, 2^{nd} Edition [24]. The ADOS-2 is a standardized, semi-structured observational assessment during which a trained clinician provides prompts and scenarios to elicit specific social behaviors (e.g., eye contact, repetitive behavior, etc.). The behaviors are then rated by the clinician. There are four modules of the ADOS-2. Three children met the cutoff for “autism” (8%), and thirty-one children met the cutoff for “autism spectrum” (78%). Six children met the criteria for “non-spectrum”. These children (as well as one additional child who had no ADOS-2 scores) were included in the ASD sample because experienced clinicians made the diagnoses on the basis of history and symptom presentation.

Verbal and nonverbal cognitive abilities were assessed with the Differential Ability Scales, 2nd Edition [25]. There are two aspects of the measure, the core and the diagnostic subtests. Only the core subtests were used in the current study, namely to measure verbal ability (verbal comprehension, naming vocabulary), nonverbal reasoning ability (picture similarities, matrices), and spatial ability (pattern construction, copying). They combine to produce a General Conceptual Ability (GCA) standard score, which was used as a proxy for the Full-Scale IQ. Depending on their age, children completed either the Early Years Battery or the School-Aged Battery of the assessment. TD children had a mean GCA of 108.6 (SD = 14.8) with a range of 77 to 141. Children with ASD had a mean GCA of 98.9 (SD = 14.5), with a range of 63 to 130. TD children had had a higher GCA than those with ASD, $t(81) = 3.04$, $p < 0.003$. However, the mean score of both groups fell into the clinically unimpaired range.

A measure of mental flexibility was obtained for a subset of children (85% of the TD group and 78% of the ASD group), using the Wisconsin Card Sorting Test, Computerized Version 4, Research Edition [26,27]. The task is to guess the category membership of test cards, receiving feedback after each trial. After the participant categorizes a number of cards correctly by a given rule, the rule is changed without informing the participant. The number of preservative errors is obtained, inverted, and standardized to correct for age (PERS). Thus a higher PERS means fewer perseverative errors committed. Reasons for missing scores include technical errors administering the test, time constraints on the part of the family, disinterest of the child, and failure to follow task instructions. There was no effect of diagnostic groups, $t(66) = 1.73$, $p = 0.09$, and the mean performance for both groups fell well within the clinically normal range.

Age was positively correlated to PERS for TD children, $r(34) = 0.40$, $p = 0.02$, but not for children with ASD, $r(30) = 0.14$, $p = 0.45$. Higher IQ was positively correlated for children with ASD, $r(30) = 0.41$, $p = 0.02$, but not for TD children, $r(34) = 0.28$, $p = 0.09$.

2.1.2. Experimental materials and setup

Stimuli consisted of cubes cut out of white foam board. They ranged in size from 2 to 20 cm wide, with 1 cm difference in cube width between adjacent cubes (yielding 19 cubes total). The foam board made it possible for cubes to be very light, allowing children to pick them up easily. No participants indicated any difficulty lifting the cubes.

A child-sized table was used, with two black curtains positioned on top of the table in such a way that they met at an obtuse angle (see Figure 1 for a schematic representation of the experimental setup). Each curtain was 30 cm high, partially occluding the front and right view of the child. A rotating wooden dolly, 36 cm in diameter, appeared to the child's left, placed in such a way that part of its surface was occluded by one of the curtains.

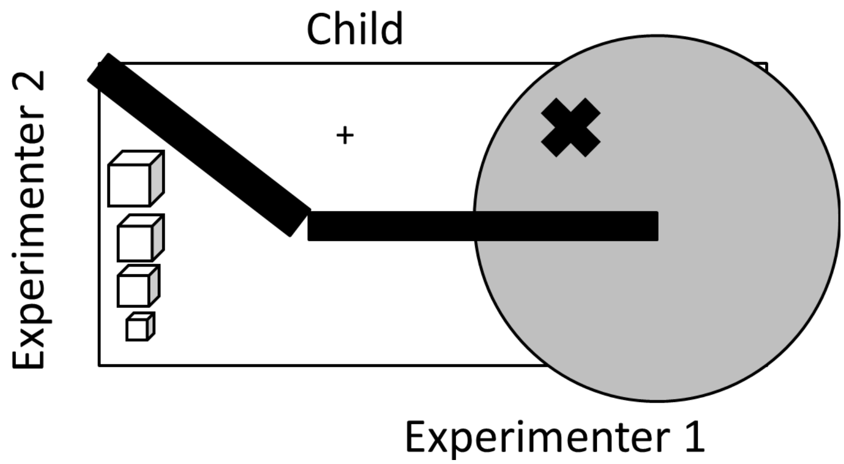

Figure 1. Diagram of experimental setup used in Experiment 1. It shows the table with cubes of various sizes, the curtains separating the child from the experimenters, and the rotating dolly. The + on the table (not seen by the child) marked the location where each cube was placed by Experimenter 2. The x on the dolly (visible to the child) marked the location the child had to move the cube to.

Participation required two visits to a large Children's Hospital in the Midwestern United States, with one visit in the clinic space and another visit in the laboratory space. During the first visit, a battery of clinical measures was administered, beginning with the Differential Ability Scales and ending with the ADOS-2. During their second visit, children completed a battery of experimental tasks, followed by the Wisconsin Card Sorting Test.

For the experimental tasks relevant to this study, two experimenters worked together: E1 and E2. Both experimenters were seated at the table behind the curtain, E1 sitting across from the child, and E2 sitting adjacent to the child, across from the dolly (Figure 1). Both experimenters were mostly out of view from the child. Children were told that boxes would be slid out from behind the curtain. During a trial, E2 slid a cube through the curtain towards the child, approximately at the position marked with + in Figure 1 (the + mark was not present in the actual setup). E1 asked the child to pick up the cube and place it on the X marked on the dolly. E1 then rotated the dolly until the cube was behind the curtain and out of view from the child. He then passed it back to E2. For each trial, E1 recorded whether the child picked up the cube with one hand or two.

Cubes were presented in two orders. In the ascending phase, participants were first presented with the 2 cm cube and then with each successively larger cube. In the descending phase, they were first presented with the 20 cm cube and then with each successively smaller cube. The maximum number of cubes presented was 19 for each of the phases. However, the number of cubes presented to each child differed as a function of the following rules: an ascending phase ended when five cubes in a row were picked up with two hands. A descending phase ended when five cubes in a row were picked up with one hand. To be included in the study, children's grasping method on the first cube of a phase had to differ from the grasping method of the last cube of that phase. Thus, children were excluded who either did not switch grasping method in at least one phase, or who switched back to their initial grasping method in at least one phase. Table 1 provides detailed information about the grasping methods of the excluded children (17% of the entire group of children tested).

Table 1. Excluded participants, including their ages, IQs, PERS, ADOS-2 scores, and their performance patterns across the conditions of experimental task.

	Experiment 1		**Experiment 2**	
Phase:	Ascending	Descending	Ascending	Descending
Excluded TD Children				
8:3 years; IQ = 103; PERS = 122	No switch			
9:5 years; IQ = 104; PERS = 99				No switch
9:4 years; IQ = 119; PERS = 99	Switched back			
8:4 years; IQ = 92; PERS = 99		Switched back		
10:3 years; IQ = 103; PERS = 110			Switched back	
9:1 years; IQ = 112; PERS = 113	Switched back	No Switch	No Switch	No Switch
7:0 years; IQ = 120; PERS = < 55	Switched back	No switch	No Switch	
10:7 years; IQ = 104; PERS = 110	No switch		Switched back	
Excluded ASD Children				
8:7 years; PERS = IQ = 89; < 55; ADOS = 18			No switch	No switch
10:6 years; IQ = 103; PERS = 98; ADOS = 10	Switched back			
7:9 years; IQ = 103; PERS = 67; ADOS = N/A			No switch	Switched back

Note: IQ was assessed with the Differential Ability Scales (2nd Edition), which returns a General Conceptual Ability standard score as a proxy for the Full-Scale IQ. PERS is a standardized score to reflect the inverse number of preservative errors obtained on the Wisconsin Card Sorting Test, Computerized Version 4. The lower the number of perseverative errors, the higher the PERS score. ADOS-2 is the score returned by the Autism Diagnostic Observation Schedule (2nd Edition), to determine diagnosis.

2.2. Results and discussion

To determine whether children showed hysteresis, a transition point was calculated in each phase, following procedures described in the literature [20,22,23]. Specifically, we identified two cubes per phase: (1) the largest cube that was grasped with one hand (with all smaller cubes being grasped with one hand); and (2) the smallest cube that was grasped with two hands (with all larger cubes being grasped with two hands as well). The transition point was the average of these two cube sizes. For example, for a particular phase, if a child used one hand for all cubes that were 10 cm and smaller, and used two hands for all cubes that were 11 cm and larger, the transition point for that phase was 10.5 cm. If this child did not consistently use two hands until the 12 cm cube, the transition point for that phase was 11 cm (i.e., the average of 10 and 12).

Figure 2 shows the average transition points for each phase (ascending vs. descending), separated by diagnostic group. As expected, the TD group demonstrated hysteresis: The transition point was higher in the ascending phase than the descending phase, paired sample $t(40) = 3.01$, $p = 0.004$. The same analysis was carried out with the ASD data. It revealed a significant difference in transition point, $t(41) = 3.99$, $p < 0.001$, children transitioned on a larger cube size in the ascending phase (from one- to two-handed grasping) than in the descending phase (from two- to one-handed grasping). Thus, like their TD counterparts, children with ASD demonstrated hysteresis during the motor task.

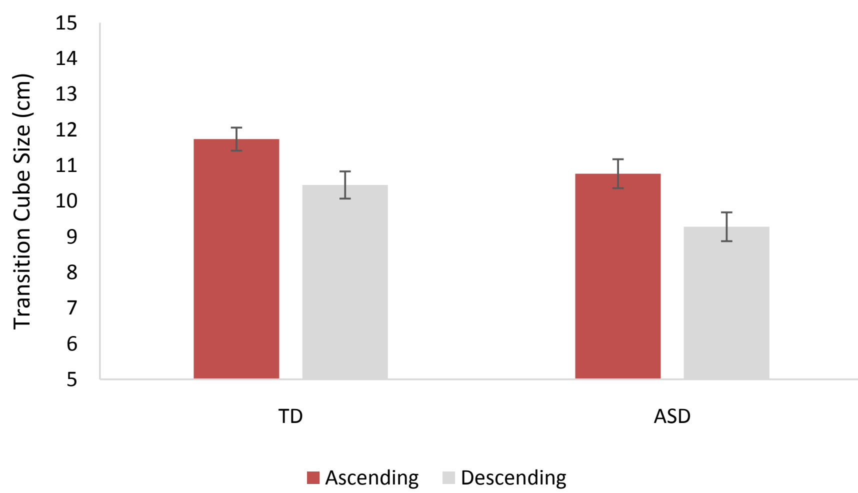

Figure 2. Mean transition point, in centimeters, for Experiment 1, separated by ascending versus descending trials, and separated by diagnostic group (TD vs. ASD).

Figure 3 shows the individual patterns of performance, separated by diagnostic group. Specifically we plotted children's difference in transition point (ascending phase minus descending phase) against their PERS (i.e., the measure of mental flexibility obtained from the Wisconsin Card Sorting Test). Note that the individual patterns of performance support the data obtained with the group averages: A majority of ASD children showed hysteresis (27/41 = 66% ASD), comparable with what was found with TD children (60%).

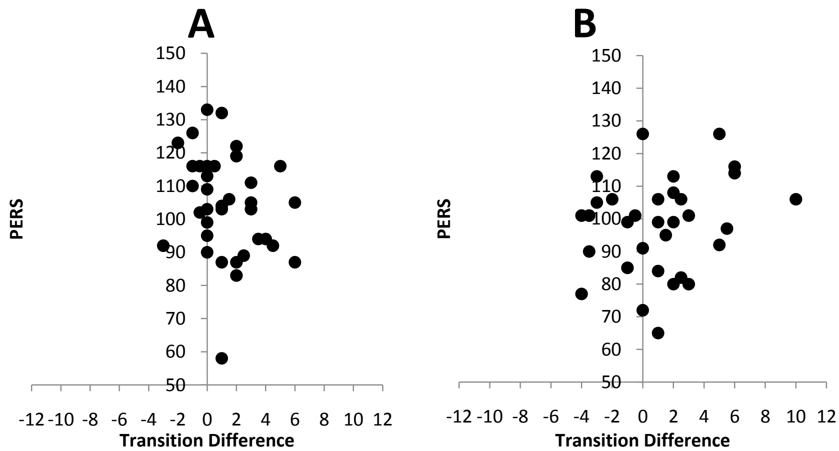

Figure 3. Scatterplot of transition difference (transition point of the ascending phase minus transition point of the descending phase) for TD children (A) and children with ASD (B), plotted against PERS in Experiment 1. PERS is a standardized score to reflect the inverse of number of preservative errors obtained on the Wisconsin Card Sorting Test. The lower the number of perseverative errors, the higher the PERS score.

The processes underlying hysteresis appear to have very little in common with the processes that govern perseveration and children's difficulty with cognitive set-shifting. The correlation between PERS and transition difference was non-significant, whether for TD participants, $r(34) = -0.24$, $p = 0.15$ or for children with ASD, $r(30) = 0.21$, $p = 0.25$. In fact, for children with ASD, the correlation between PERS and transition difference was in the opposite direction of what would be predicted by a model that equates hysteresis with perseverative error.

3. Experiment 2

So far, we have established that the grasping task elicits hysteresis for ASD children, similar to the levels seen in TD children. The next question is whether hysteresis is visible when a social component is added to the motor task. To answer this question, we modified the grasping task so that children were asked to hand the cubes to the experimenter seated across the table from them (rather than placing the cubes on the dolly).

3.1. Method

3.1.1. Participants

The children who participated in Experiment 1 also participated in Experiment 2.

3.1.2. Materials, procedure and design

All children completed Experiment 1 first, and then Experiment 2, both in the same session, and both making use of the same materials, setup, and experimenters. For this experiment, the dolly turntable was removed, along with the curtain that was between the child and E1. E2 remained hidden behind the curtain, moving one cube after the next through the curtain. E1 asked the child to pick up the cube and hand it to him. He positioned his hands so that they corresponded to the same location as the X on the turntable. Everything else stayed the same. Children who were presented with the ascending phase first in Experiment 1 were presented with the ascending phase first in Experiment 2 and vice versa. E1 held out either one hand or two, which was a between-subjects manipulation.

3.2. Results and discussion

We determined again a transition point for each child, namely to capture the size of the cube at which a child switched from how the cube was held (e.g., transition point from holding the cube with one hand vs. two hands). Figure 4 provides the obtained average transition points, separated by diagnostic group (TD vs. ASD), phase (ascending vs. descending), and condition (one-hand vs. two-hand).

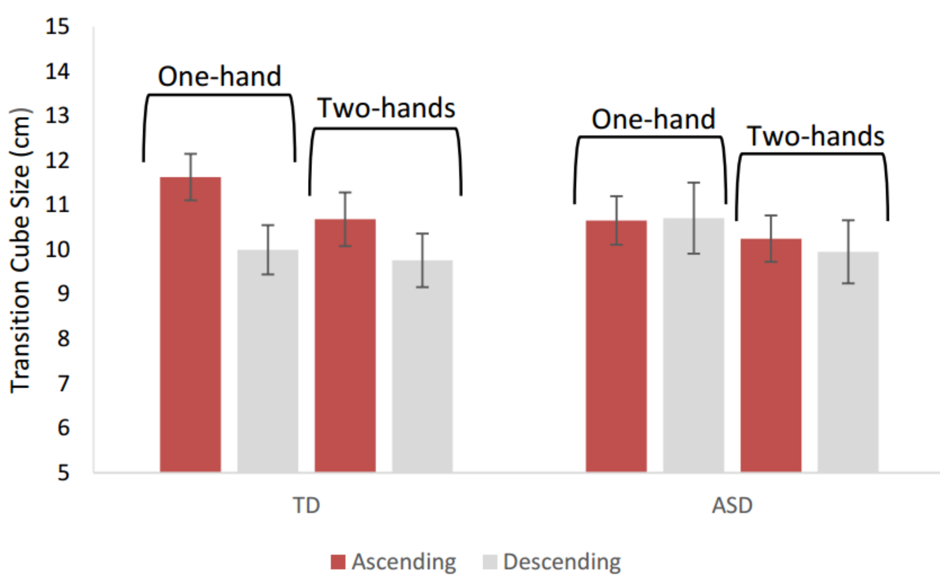

Figure 4. Mean transition point, in centimeters, for Experiment 2, separated by phase (ascending vs. descending), condition (one-hand vs. two-hand), and diagnostic group (TD vs. ASD).

We looked at TD performance first, to establish the degree to which the task elicited hysteresis. A 2 × 2 mixed-design ANOVA was carried out, with condition (one-hand vs. two-hand) as the between-group factor, and phase (ascending vs. descending) as the within-group factor. As expected, we found a significant main effect of phase, $F(1,40) = 5.73$, $p = 0.02$, with a higher transition point in the ascending phase ($M = 11.20$) than in the descending phase ($M = 9.89$). There was no main effect of condition, $p > 0.30$, and no interaction with condition, $p > 0.50$. Thus, regardless of whether the experimenter held up one or two hands when receiving the cube, TD children showed evidence of hysteresis.

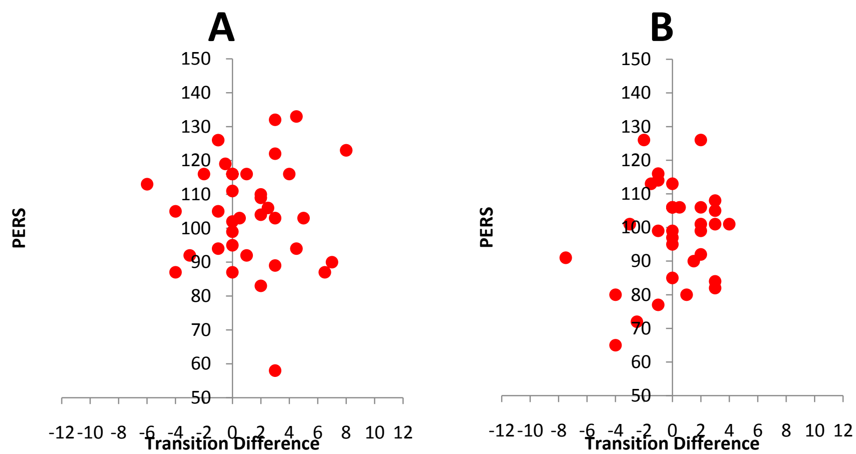

Figure 5. Scatterplot of transition difference (transition point of the ascending phase minus transition point of the descending phase) for TD children (A) and children with ASD (B), plotted against PERS in Experiment 2. PERS is a standardized score to reflect the inverse of number of preservative errors obtained on the Wisconsin Card Sorting Test. The lower the number of perseverative errors, the higher the PERS score.

This finding mimics what we found for TD children in the motor task of Experiment 1, when children had to place the cubes on the dolly, rather than handing them to the experimenter. Indeed, a 2 × 2 (experiment by phase) repeated-measure ANOVA revealed a main effect of phase, $F(1,41) = 22.19$, $p < 0.01$, an effect that held up when TD data was analyzed separately for each condition (one-hand condition: $F(1,22) = 10.46$, $p = 0.004$; two-hand condition: $F(1,18) = 11.36$, $p = 0.003$). Importantly, there was no experiment-by-phase interaction, whether across conditions, $p > 0.97$, or within each separate condition, $ps > 0.27$. And there was no main effect of experiment, whether when collapsed across conditions, $p > 0.08$, or when analyzed separately for condition, $ps > 0.16$.

Now consider children with ASD. The condition-by-phase mixed-design ANOVA found no main effect of phase, $p > 0.76$, nor an interaction with phase, $p > 0.66$. Whether cubes were presented in ascending or descending order, the transition point did not differ. Thus, children with ASD transitioned on similarly sized cubes in both the ascending and descending phases, failing to demonstrate hysteresis when they had to hand the cube to the experimenter. The simple action of handing the cube to a person, rather than placing it on the dolly, yielded a different pattern of results (see Figure 5 for the individual patterns of performance). A 2 × 2 (experiment by phase) repeated-measures ANOVA returned a significant interaction, $F(1,40) = 5.05$, $p = 0.03$, with an effect of phase in Experiment 1, $t(41) = 3.99$, $p < 0.01$, but no effect of phase in Experiment 2, $t(40) = 0.34$, $p = 0.74$. This interaction even held up when it was conducted for the two-hand condition only, $F(1,21) = 8.17$, $p = 0.01$. Thus, there is indication that ASD performance in a pure motor task differed from performance in a motor task that included a social component.

4. General Discussion

Fueled by the idea that ASD affects higher-order dynamics of adaptive behavior, we set out to explore hysteresis in children with ASD through a cube grasping paradigm. Three results stand out: First, children with ASD showed hysteresis (Experiment 1). Their performance was unrelated to mental-flexibility scores, suggesting that hysteresis is an adaptive behavior of the system, not a failure to switch from one behavior to another. Second, hysteresis decreased markedly for children with ASD in Experiment 2, when a social component was added to the task. When children had to pass the cubes to the experimenter, rather than place them on a dolly, hysteresis disappeared. Third, the ASD finding in the social scenario differed from the TD finding in the social scenario, but not in the motor task per se, suggesting that the difference in higher-order dynamics between ASD and TD is confined to the social realm. We will discuss each result in turn.

4.1. Hysteresis and ASD

To our knowledge, the current study is the first to document hysteresis in children with ASD. In Experiment 1, children's behavior changed in critical ways when cubes were presented in ascending order (from smallest to largest), then when the cubes were presented in descending order (from largest to smallest). Specifically, when cubes were presented in ascending order, children switched their grasping pattern at a larger cube than when cubes were presented in descending order. This was the case for both diagnostic groups (TD and ASD), with no difference at the level of individuals.

Importantly, we found that the level of hysteresis (the difference in transition point between ascending and descending phase) was unrelated to a child's performance on the mental-flexibility task. While this is merely a null-effect, it is telling that the correlation was in the opposite direction than what would have been predicted if hysteresis is nothing more than an issue of perseveration.

This finding is in line with previous claims that hysteresis is something different than the non-adaptive failure to switch appropriately [28,29]. The current results provide further evidence for this differentiation between hysteresis and perseveration.

Like TD children, performance of children with ASD was affected by its immediate history. Documenting hysteresis in ASD implies the capacity for adaptive functioning within favorable contextual factors. This is in line with other studies that have demonstrated that children with ASD can demonstrate adaptive coordination [10] depending on task constraints. However, previous work has generally focused on achievement; that is, whether a child passed or failed a task. In the current paradigm, both TD children and those with ASD could complete the task successfully; they could pick up the cubes and move them to the appropriate position. The important factor was the manner in which they did so. Both groups demonstrated hysteresis.

The importance of both groups demonstrating hysteresis goes beyond an indication of adaptive functioning. Hysteresis is an indicator of a multi-stable (or meta-stable) nonlinear system [4,22,30]. Its presence is a sign that the behaviors involved in completion of the experimental task can be conceptualized as a complex system. That is, performance cannot be broken down into components that interact in a linear and sequential fashion, but rather emerges as a result of the coordination between numerous factors coordinating in a nonlinear manner. Said differently, it provides indication that behavior cannot necessarily be accurately depicted through reductionist models, but should rather be contemplated under an interaction-dominant lens.

4.2. Disrupted Hysteresis in the Social Scenario

Patterns of performance changed when children with ASD where asked to hand the cube to the experimenter (Exp. 2), rather than place the cube on a dolly (Exp. 1). This social-scenario task, to hand the cubes to the experimenter, was virtually identical to the task that did not require a social interaction: The same two experimenters were present in both settings, and their relative position to the child remained the same. Similarly, the cubes and motor task of picking up a cube and moving it to a new location remained the same, with no change in the physics of grasping. Even the trajectory of moving the cubes remained largely the same. The only difference then was in the interaction between the child and one of the experimenters: While the child merely had to follow the experimenter's instructions in Experiment 1 (to place the cube on the dolly), a direct interaction was required in Experiment 2 (when the child had to hand the cube to the experimenter).

And yet, despite such subtle changes in the task context, the amount of hysteresis decreased. The overall average transition point did not change ($M_{\text{Exp. 1}} = 10.02$; $M_{\text{Exp. 2}} = 10.39$) suggesting that children still showed the same grasping behavior overall, whether when having to place the cube on the dolly or into the hands of the experimenter. But the change in social context changed the dynamics of behavior: In the motor task, when social interactions were minimal, the immediate history affected the grasping behavior. And in the social scenario, when children had to give the cubes to the experimenter, the immediate history ceased to matter. While children could still complete the task the same way as before, the requirement to interact with a person changed the dynamics of performance [31].

One could argue that this change in behavior is the result of the order in which the experiments were presented: Given that Experiment 2 took place after Experiment 1, children might have been fatigued or have lost interest in the task. However, previous research has shown that hysteresis increases, not decreases, when participants are distracted. This was the case when Lopresti-Goodman and colleagues (2009) instructed participants in a grasping paradigm to count backwards from a random digit by sevens. Thus, for the current study, finding less, not more hysteresis, rules out this possibility.

The degree to which the performance patterns of children with ASD was affected by the presence of a person seeking to interact with them raises questions regarding intervention strategies that involve interacting with another human. There is increased interest in using technology as a therapeutic interface [32], with focus being given to the potential therapeutic utility of robotics [33]. The rationale is that children with ASD respond better to feedback from technology than from humans [34,35]. Our findings lend support to this reasoning: Given that dynamics of behavior lost their complexity flags in the social scenario, interventions delivered in a non-social scenario may be beneficial.

4.3. Dynamics in TD vs. ASD

The question of the sources of atypical versus typical behavior has high currency. And indeed there are many differences between TD and ASD, including social-interaction style, communication, and perception. Here we add one more difference: The dynamics of behavior displayed in the social scenario differed between ASD and TD. Specifically, while both groups of children showed hysteresis in the pure motor task, there was a significant difference in hysteresis in the social scenario: Hysteresis was lower for ASD than TD. In other words, while overall performance success in the social scenario remained the same across the two diagnostic groups, the type of dynamics was not. To what extent does this finding shed light on the core difference between TD and ASD?

First, note that a lack of hysteresis is not automatically a problem. There are many task contexts that elicit critical-value behavior in typically developing adults, where a change in bi-stable behavior is affected by the physical properties of objects, not the immediate history or the anticipated future [20]. Speed of object presentation, for example, affects the demonstration of hysteresis: TD individuals tend to show more hysteresis when working quickly. And hysteresis may disappear when working very slowly. It is also possible for children to demonstrate enhanced contrast, rather than hysteresis, such as if learning occurs. Enhanced contrast is the signature of an anticipatory system, where the person changes faster than physically necessary, in anticipation of the behavior required on future trials, due to perceived differences. Thus, the change in patterns of hysteresis implies the presence of a different kind of system, not a deficient or mistaken system [30].

Finding difference in the dynamics between TD and ASD, not in overall performance success, adds an important puzzle piece to the speculations about core differences between these two groups. As opposed to providing evidence for global deficits in either social or motor functioning, findings suggest differing patterns of coordination between domains. It appears that the requirement to interact with another person affected the ASD system but not the TD system. And it did so pervasively, even if the task was as grounded as the grasping of objects. More specifically, the required social interactions appear to have reduced the glue between experiences, a glue that remained intact for TD children.

The idea that the presence of a person affects how experiences are connected to each other, rather than the individual experience, fits with a number of previous ASD findings. For example, it can explain why children with ASD are less likely to adapt appropriately to social interactions [36]. Their tendency for difficulty switching between tasks may represent not inflexibility, but rather distress related to difficulty applying prior knowledge. Finally, it can explain why language learning is a serious challenge for children with ASD, given that language learning depends on discovering overarching statistical regularities. Without connecting one experience to the next, the commonalities that make up syntax and semantics remain hidden.

5. Conclusion

The current project took on a conceptualization of ASD that moves away from a reductionist understanding of symptomology. We subscribe instead to the idea that moment-to-moment changes in behavior shed light on how behavior that is coordinated at the macro-level can unravel the dynamics of development. This viewpoint may help unify many of the conflicting findings associated with ASD task completion. The varied performance of individuals with ASD on different tasks is often considered problematic because of the search for a core deficit. If such tasks are approached through the lens of the coordination account, focus shifts to the effect of contextual factors on how tasks are completed. Thus, differences in performance can be explained through a common phenomenon. This may facilitate the development of new assessment and intervention modalities in the future.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

Author Note

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