

Article

The Association among Autistic Traits, Interactional Synchrony and Typical Pattern of Motor Planning and Execution in Neurotypical Individuals

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Abstract: Autism spectrum disorder (ASD) is characterized by deficits in interactional synchrony and motor performance, but little is known about the association between them. The current study investigated the association among aberrant interactional synchrony (as measured by interactors' symmetry in the form of the hand at each time-point along movement's execution), motor functioning and the level of Autistic traits. In this study, autistic traits were evaluated by the Autistic Spectrum Quotient (AQ). Two tasks were used: (1) an interactional synchrony task where participants and the research assistant were instructed to move their hands together; and (2) a motor planning task which allows for continuous monitoring of natural hand movements. Pearson correlation analysis indicated a significant association between lower communication skills (i.e., higher AQ communication scores) and lower intentional synchrony rates. In addition, lower communication skills were found associated with typical patterns of motor planning and execution characterized by shorter time to start the movement and higher value of max speed. Mediator analyses supported the notion that aberrant intentional synchrony in individuals with low communication skills is partially mediated through typical patterns of motor planning and execution. These results suggest typical patterns of motor functions may account for intentional synchrony difficulties.

Keywords: ASD; autistic traits; interactional synchrony; motor planning and execution



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1. Introduction

1.1. Autism Spectrum Disorder

Autism spectrum disorder (ASD) is one of the most common childhood neurodevelopmental disorders [1]. It is characterized by difficulties in social interaction and communication, restricted interests and repetitive behaviors [2].

Interestingly, it has been shown that ASD is characterized by fundamental deficits in motor functioning [3–5]. The possibility that these deficits might have an effect on various aspects of social and communication functioning, including poorer social responsiveness, imitation and interpersonal synchrony [6,7], has thus far received little attention.

In the current study, we sought to examine the link between two very different symptoms, namely interactional synchronization and motor function, which have thus far have been studied separately. As such, the co-occurrence of these two symptoms has been critically underappreciated.

1.2. Interactional Synchronization

During social interaction, people tend to mimic and synchronize. Hove and Risen (2009) suggested that there are two types of interpersonal coordination: behavior matching

(e.g., mimicry and imitation) and interactional synchrony [8]. Interactional synchrony refers to alignment in both form and time, whereas behavior matching simply requires that actions match in form. Given the crucial aspect of time in interactional synchrony, most recent approaches that have been developed to measure interactional synchrony have focused on matching in time and less attention has been paid to whether or not interactive individuals match the form of their hands. For example, in the mirror game paradigm, where participants are instructed to move handles across tracks and synchrony is measured by similarity in the velocity and characteristics of the movement [9], such approaches do not consider similarity of the form of the hand.

Hence, the present study employed a novel approach to measure interactional synchrony by focusing on alignment in both the form of the hand and time.

A growing body of literature suggests that interactional synchrony plays a crucial role in the beneficial consequences of social interactions [10]. It increases group cohesion, affiliation and social cooperation between adults [8,11,12]. Moreover, it promotes compliance, conformist behavior [13,14] and trust [15]. In addition, it encourages compassion, altruism [11] and verbal communication and comprehension [16].

Given the link between prosocial behavior and interactional synchrony, it is not surprising that aberrant interactional synchrony has been found in individuals with disruption of social functioning, for instance, individuals with social anxiety disorder [17] or those with ASD [6].

1.3. Aberrant Interactional Synchrony of People with Autism

As mentioned above, individuals with ASD have deficits in various social abilities [18]. These include impairments of gesture, facial expression and vocalization imitation [19–21]. In addition, a central deficit of autism is Theory of Mind functioning, which manifests itself as the inability to relate mental states such as intentions, beliefs and desires that belong to them or other people. This in turn hinders the ability to understand and predict behavior [22].

Notably, recent evidence suggests that ASD is associated with aberrant interactional synchrony. For example, unlike typical development (TD) children, children with autism exhibit weaker spontaneous interactional synchrony while sitting next to their parents on separate rocking chairs [6]. Likewise, adolescents with ASD showed lower levels of synchrony ability with their parents during spontaneous and intentional pendulum synchrony tasks compared to TD adolescents [23]. Even more, adolescents with ASD also demonstrated less synchrony of speech and gesture [24]. Additionally, a recent study showed that individuals with high autistic traits tend to display a reduced spontaneous synchrony in human groups compared to individuals with low autistic traits. However, this tendency is recovered when synchrony is intentional [25]. Finally, adults with ASD exhibit a reduced ability in their modification of grasping movements in a task that required a synchrony of their movements with their respective partners [26].

Collectively, these studies provide evidence for aberrant interactional synchrony in individuals with autism and raise the possibility that the link between ASD and the aberrant form of interactional synchrony reflects their deficits in social interaction. However, it is reasonable to assume that it may also reflect their motor dysfunctions. To the best of our knowledge, this question has so far received little research attention.

1.4. Motor Abnormalities in ASD

Individuals with ASD show impairments in motor performance from an early age [6,27–30]. Additionally, high-risk infants who then develop ASD usually have deficits in motor skills at age six months [31]. A recent meta-analysis by Mosconi and Sweeney (2015) showed that motor dysfunctions can be in gross and fine motor movements, balance skills, oculomotor functions and praxis [32].

As mentioned above, individuals with ASD show reduced general motor performance in comparison to TD individuals [9]. Motor performance was assessed by The Revised

Neurological Examination for Subtle Signs (PANESS) [33], which measures robust movements, e.g., the amount of hand-taps or the amount of hops on one leg in a particular time. Motor planning, an internal representation of the motor movement [34], was investigated in several disorders associated with motor dysfunctions. Given the crucial role that motor planning plays in any type of motor performance, it is quite surprising that the question of whether ASD is associated with deficits in motor planning has thus far received relatively little research attention.

The first stage of motor execution is motor planning. Before performing a motor action such as a reaching movement, a movement plan needs to be developed [34]. Findings related to motor planning in ASD are mixed [35]. In simple tasks, such as drawing a line between two targets, similar performances were found for children with ASD and TD [36]. However, when presented with more complex tasks that manipulate the size and distance of targets and valid and invalid movement cues [37,38], adults with ASD required more time to start their movements and had a movement with lower peak acceleration and speed than TD adults.

Previous studies suggest that motor abnormality is a factor that may be directly related to the ability of connecting with others among individuals with ASD [4,6,19,39]. Leary and Hill (1996) suggested that movement disturbances in individuals with autism may have a significant negative effect on their social relationships [40]. According to them, movement disturbances include impairments in motor function such as posture and muscle tone, impairments in volitional movements such as language disturbances and impairments in motor functioning that affect overall behavior and activity such as no or impaired imitation and lack of initiation [40]. Moreover, Cossu et al. (2012) examined the relation between ASD and action understanding based on motor cues [41]. Their results reveal that children with ASD were significantly worse than the two control samples in all three motor cognition domains: action imitation, pantomime production and comprehension of observed pantomimes [41]. Additionally, several studies found that deficits in either gross motor skills (e.g., running and jumping) or interpersonal coordination can restrict children's friendships and social interactions [40,42]. Likewise, reduced manual motor skills were found to affect nonverbal modes of communication, such as deficits in pointing a finger toward a stimulus [43].

1.5. Is There a Link between Motor Abnormalities and Aberrant Interactional Synchrony in ASD?

Thus far, only a few studies have addressed the question of whether deficits in interactional synchrony in ASD can be accounted for, at least partly, by their motor deficits. For example, Brezis et al. (2017) used the mirror game paradigm [44] to examine synchrony during open-ended interactions [9]. They revealed that individuals with ASD display shorter duration of synchrony and that they have reduced interactional synchrony. Moreover, they found that individuals with ASD showed reduced general motor performance compared to TD individuals. Critically, the deficits in motor function of individuals with ASD was found to predict their difficulties in interactional synchrony. However, while Brezis et al. (2017) assessed macro-behaviors (e.g., observable motor tasks) [9], the link between micro-behaviors—motor planning measures such as start time—and execution measures—such as velocity—together with the ability to synchronize with others has yet to be elucidated. A recent model proposed by Gvirts and Dahan (2021) [45] suggests that interpersonal synchronization and motor functioning share a common neurobiological mechanism and adhere to the same principles of predictive coding. Importantly, they describe the pivotal role of the dopaminergic system in modulating these two distinct functions.

In the current study, we examined, to our knowledge for the first time, the link between motor planning and execution and interactional synchrony by focusing on timing and hand movement in relation to the level of autistic traits. The simplest way to evaluate motor planning and execution is by recording the reaction time that it takes to devise a motor plan [46]. Thus, this may be specifically relevant for the ability to synchronize with others. Here, we sought to examine whether motor abnormalities in individuals with many autistic

traits mediated the association between autistic traits and aberrant forms of interactional synchrony. This was examined by a recently developed motor planning task [47], where hand movements were continuously measured after different planning intervals.

As noted above, the current study employs a novel approach to measure interactional synchrony by focusing on alignment in both hand form and time. To this end, a novel task for measuring joint movement of two hands was developed. The hand movements are measured using a Leap Motion depth 3D sensor that is specifically designed for measuring hand gestures (at 100 Hz). During the task, the participant and the research assistant sit on two sides of a table, lifting their hands above the Leap Motion depth sensor, and are asked to move together. We then assessed whether we found symmetry in the form of the hand movement as it was performed by them.

The proposed study sought to clarify and investigate the connection between motor planning and execution and interactional synchrony in healthy individuals. We hypothesized that typical patterns of motor planning and execution of individuals with many autistic traits create greater difficulty for synchronization of their movement timing with others, possibly resulting in reduced interactional synchrony.

Autistic traits are distributed on a continuum ranging from extreme to normal scores, which reflect the variation of the autistic traits across the general population [48]. Thus, similar to numerous studies [25,49–51], the current study focused on individuals who are not diagnosed with ASD, but who vary in their possession of autistic traits.

1.6. Aims and Hypotheses

Our study aimed, to our knowledge for the first time: (1) to assess the association between autistic traits and interactional synchrony measured by similarity of hand form movement in any given time; (2) to assess the association between autistic traits and motor planning and execution; and (3) to examine whether typical patterns of motor planning and execution mediate the association between autistic traits and aberrant forms of interactional synchrony.

Based on previous findings that link ASD and interactional synchrony deficits [6,9,23], we hypothesized that autistic traits would be negatively associated with interactional synchrony rates. Secondly, given that individuals with ASD display longer reaction times than the control group [38,52], we hypothesized that autistic traits would be positively associated with typical patterns of motor planning and execution performance. Finally, given that motor performance is required for interactional synchrony [23], we assumed that typical patterns of motor planning and execution would mediate the association between high autistic traits and aberrant forms of interactional synchrony.

2. Materials and Methods

2.1. Participants

Thirty healthy undergraduate students (13 male and 17 female) aged 20–30 years old ($M = 24.3$, $SD = 2.6$) participated in the study: 17 study exact science and 13 social science. Chi-square analysis was conducted to examine the association between the level of autistic traits (high/low according to median split) and the faculty (social science/exact science). This analysis revealed marginally significant differences in the distribution of faculty of study between the high AQ and low AQ groups, $\chi^2(1) = 3.40$, $p = 0.065$.

They were recruited from the University of Ariel, Israel, and they received a course credit or a payment. Exclusion criteria were: (a) background of neurological or psychiatric illness; or (b) participants reporting previous acquaintance with the research assistant. All participants were naive about the aim of the study and none of them reported taking any psychoactive medication.

2.2. Tools

2.2.1. Autism Spectrum Quotient (AQ)

Autism Spectrum Quotient (AQ) is a 50-point self-report scale. It was developed to assess the extent to which an adult with average intelligence has autistic traits. In the questionnaire, participants rate their own behavior in the subscales of social skills, attention switching, attention to detail, communication and imagination on a four-point scale (definitely agree, slightly agree, slightly disagree, definitely disagree) [53]. Higher scores indicate greater numbers of autistic-like traits.

2.2.2. The Leap Motion Device

The position of the hands was recorded using a Leap Motion Device. This is a 3D depth sensor that is targeted to measurements of hand gestures with no need for holding a handle or controller. Hand positions are recorded at 100 Hz, and then extracted using the system development kit (SDK). For this task, a Python logger was used to extract the parameters from the SDK, including 3D hand positions and velocities. This tool provides rich and novel sources for measuring 3D synchronization of hand positions in an ecologically valid manner (URL: <https://www.leapmotion.com> (accessed on 21 August 2007)).

During the task, the research assistant and participant sit on two sides of a table, lifting their hands above a Leap Motion depth sensor (see Figure 1). Participants were instructed to limit their movements to an area above the sensor. The Leap Motion logger recorded hand movement for both research assistant and participant. This device provides means of capturing and tracking the fine movements of both hands and fingers, while controlling a virtual environment requiring hand–arm synchrony as part of the practicing of virtual tasks [54,55].



Figure 1. The participant and the research assistant sat on different sides of the table and were asked to move their hands above the Leap Motion depth sensor.

The experiment comprised two conditions: uninstructed and instructed. The uninstructed condition included alone-participant and alone-assistant, whereas the instructed condition included intentional synchrony rounds and spontaneous rounds synchrony (see Figure 2). During the alone round, the participant or assistant turned his back while the other was asked to move his hand freely above the Leap Motion controller. In the spontaneous synchrony round, they were asked to move freely as they wished. In the intentional synchrony round, they were asked to move in synchrony. They were invited to interpret synchrony as they understood it. In these two rounds, the participant and assistant were in front of each other.

Scoring of the interactional synchrony: The data of the uninstructed condition (alone-participant, alone-assistant and spontaneous) served as a control condition. The alone round was analyzed as if it consisted of a face-to-face interaction (i.e., alone round); that is, the recording of the participant and research assistant were combined and analyzed as if they were taken from the same session.

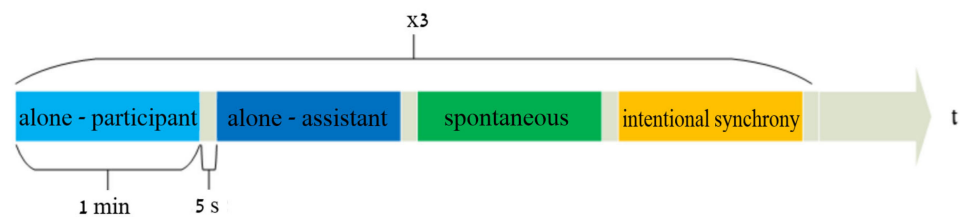


Figure 2. The experiment included four types of rounds that were given in the following order: (1,2) alone-participant/alone-assistant; (3) spontaneous; and (4) intentional synchrony. Each round lasts 1 min with a 5 s pause between conditions. Each condition is repeated three times. The interaction between players is created by movement, and they were not allowed to communicate.

For each of the three types of rounds (i.e., alone, spontaneous and intentional synchrony), we assessed interactional synchrony by evaluating the symmetry of the form of the hand and fingers. This positioning was measured by two parameters: Grabbing and Pinching. Grabbing assesses the rates of the palm closing, while pinching assesses the proximity between the two fingers. The symmetry of the form of the hand between the participant was calculated by the difference between participant and research assistant at each point of time: $\Delta grab = grab1 - grab2$; $\Delta pinch = pinch1 - pinch2$. Accordingly, the parameters measuring similarity at each point in time were defined as follows:

Grabsync (the similarity between the grabbing of two participants) = $1 - |\Delta grab|$
 Pinchsync (the similarity between the pinching of two participants) = $1 - |\Delta pinch|$

Higher interactional synchrony referred to a higher score in these measures. In other words, in the case participant and research assistant performed the same form of movement (i.e., both performed grabbing or pinching), their score was one. However, if their movement was different (e.g., only one of them was performing pinching or grabbing), then their scoring was zero. Note that, for each sample, Grabsync or Pinchsync ranged 0–1. Higher scores during the alone condition indicate that the participant and the research assistant showed symmetry in their tendency to close their hands and pinch with the fingers when they were asked to move their hand freely.

Finally, each block was averaged to obtain six scores of interactional synchrony: two (one for Grabsync and one for Pinchsync) for each of the three conditions (i.e., alone, spontaneous and intentional synchrony). A high score at a certain time point of Grabsync and Pinchsync indicated a high similarity of form. As Grabsync and Pinchsync were calculated at each point of time (each frame in the leap motion), having a high average score accounts for an alignment in time.

2.2.3. Motor Planning Task

Motor Planning Task assessed motor planning and execution [47], but it was slightly modified to enable portability, i.e., working on a 10-inch tablet. The task allows continuous monitoring of natural hand movements and a comparison of such movements after sufficient (long) and insufficient (short) planning intervals. As noted above, in complex tasks, adults with ASD showed lower performance in motor functions [37,38]; therefore, in the current study, we focused on the short planning condition that serves as the complex condition.

During the task, the participant was instructed to move his finger from the starting point to one of four possible target locations, as the fourth of four beeps is heard, while avoiding obstacles on the way. The selected target appears at one of four possible locations at a short planning interval (25 ms before the last beep). The task includes 24 trials, and, in each of them, the trajectory path was recorded (see Figure 3).

The scoring was calculated by three measurements that relate to motor planning and motor execution (dependent variables): (1) time of start of movement; (2) time of max speed; and (3) value of max speed.

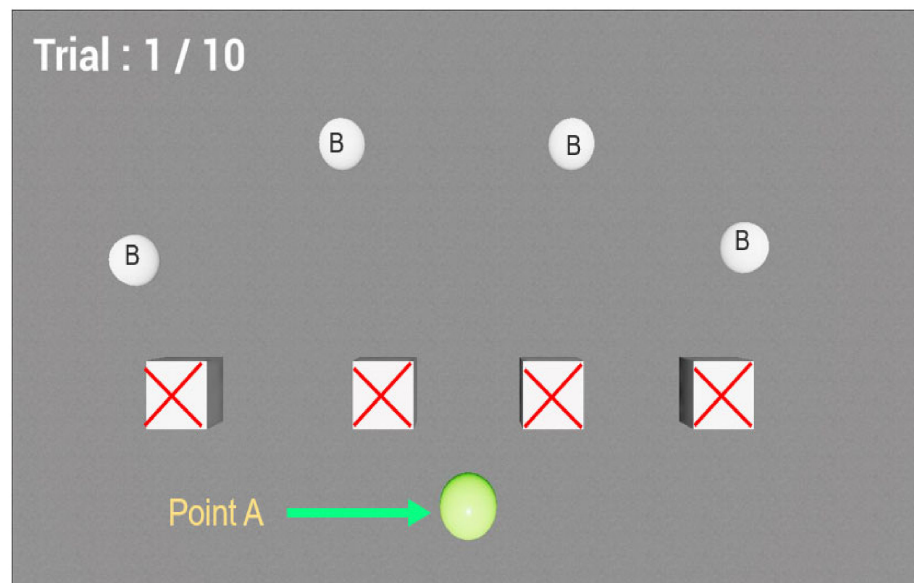


Figure 3. Portable (tablet) version of the motor planning task. The participant will need to reach from starting point A which will always be fixed and visible, to a target point B while avoiding obstacles on the way.

3. Statistical Analysis

Since the task is a novel one, our first goal was to validate that the task measures both spontaneous and intentional synchrony; that is, to validate that synchrony is higher in these two conditions as compared to the control condition. To this end, we conducted a repeated-measure one-way ANOVA, with condition (control, spontaneous and intentional) as the within-subject factor. Follow-up paired t-tests were conducted to determine the nature of the effects.

To examine the first and second hypotheses, Pearson correlation was used to assess the correlations among the AQ subscales ((1) social skill; (2) attention switching; (3) attention to detail; (4) communication; and (5) imagination), the measures of motor planning and execution ((1) time of start of movement; (2) time of max speed; and (3) value of max speed) and the measures of interactional synchrony form ((1) Pinchsync; and (2) Grabsync) for each of the three conditions (control, spontaneous and intentional synchrony).

To examine the third hypothesis of evaluating the mediation of the typical pattern of motor planning and execution in the association between AQ and interactional synchrony, we used SPSS Model 6 from PROCESS macro [56]. Various measures of effect size, standard errors and confidence intervals for indirect effects were assessed. According to Baron and Kenny (1986), three conditions have to exist for estimating mediation [57]: (1) the independent (X: AQ) and the dependent (Y: interactional synchrony) variables are significantly correlated; (2) the independent variable (X: AQ) and the mediator (M: typical pattern of motor planning and execution) are significantly correlated; and (3) the mediator (M: typical pattern of motor planning and execution) is a significant predictor of the dependent variable (Y: interactional synchrony), while adjusting the independent variable (X: AQ). Then, the bootstrap procedure proposed by Preacher and Hayes (2004) with 95% bias-corrected confidence intervals was used for estimating indirect effects, using 1000 bootstrap samples [58]. Note that a confidence interval that does not exceed zero value indicates a significant indirect effect.

4. Results

4.1. Task Validation

The repeated-measure one-way ANOVA revealed the main effect for condition ($F(2, 58) = 69.265, p < 0.001$). Follow-up paired t-tests confirmed that Pinchsync was

higher in intentional synchrony as compared to the control ($t(29) = -9.047, p < 0.001$). However, Pinchsync was lower in the spontaneous condition as compared to the control ($t(29) = 2.707, p < 0.05$).

Additionally, repeated-measure one-way ANOVA revealed the main effect for condition ($F(2, 58) = 52.597, p < 0.001$). Follow-up paired t-tests confirmed that Grabsync was higher in intentional synchrony as compared to the control ($t(29) = -6.999, p < 0.001$). However, Grabsync was lower in the spontaneous condition as compared to the control ($t(29) = 2.321, p < 0.05$). Accordingly, we conclude that synchrony emerges in the intentional condition but not in the spontaneous condition. Hence, all subsequent analyses were conducted on the intentional synchrony condition.

4.2. Correlation Analysis

As noted above, we examined the association among autistic traits (AQ), motor planning and execution and interactional synchrony measurements. These correlations were non-significant in control and spontaneous conditions (not presented). However, in intentional synchrony condition, the AQ communication subscale was found to be significantly associated with intentional synchrony (see Table A1 in Appendix A) and motor planning and execution (see Table A2 in Appendix A) measurements.

As shown in Figure 4, we found a significant negative correlation between AQ communication and Pinchsync ($r = -0.51, p < 0.01$). Likewise, a negative correlation between AQ and Grabsync was marginally significant ($r = -0.36, p = 0.051$), suggesting that individuals with higher autistic traits show aberrant forms of intentional synchrony. Additionally, we found significant negative correlations between AQ communication and time of start of movement ($r = -0.44, p < 0.05$) and between time of start of movement and value of max speed ($r = -0.49, p < 0.01$). These results indicate that individuals with high autistic traits show typical motor planning and execution of short reaction time and high value of max speed. Furthermore, significant negative correlations were found between the value of max speed and both Pinchsync ($r = -0.43, p < 0.05$) and Grabsync ($r = -0.54, p < 0.01$), suggesting that high value of max speed is linked to aberrant forms of intentional synchrony (see Table A3 in Appendix A).

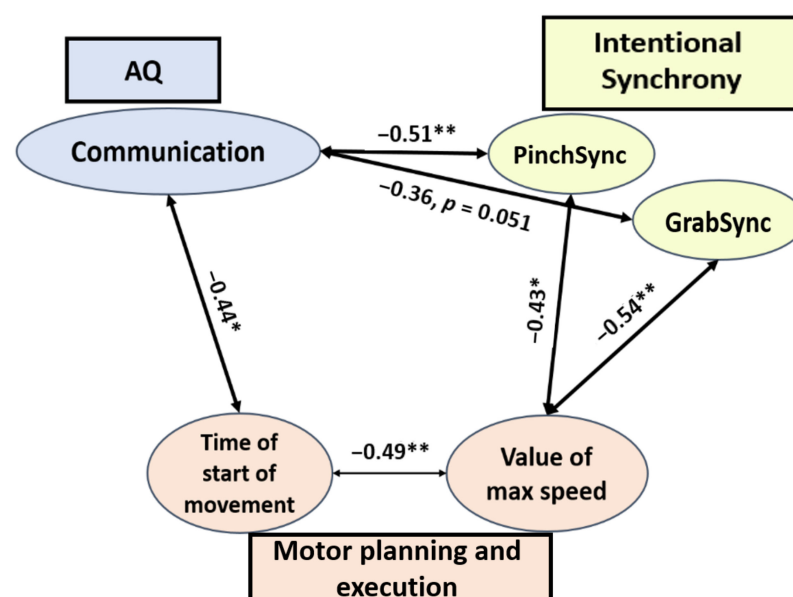


Figure 4. Correlations among AQ communication subscale (marked in blue), intentional synchrony (marked in yellow) and motor planning and execution (marked in red) measurements. AQ, Autism Spectrum Quotient. The displayed values are Pearson correlation coefficients. * $p < 0.05$; ** $p < 0.01$.

4.3. Mediation Analysis

To clarify the mediator role of the typical pattern of motor planning and execution, mediator analyses were conducted to determine the extent to which motor functioning explained intentional synchrony. The independent variable was AQ communication; the mediators were time of start of movement and value of max speed; and the dependent variable was different types of intentional synchrony form (i.e., Grabsync and Pinchsync). According to Baron and Kenny's approach (1986) mentioned above, the three conditions exist [57].

The analysis revealed a marginally significant direct effect of AQ communication on Grabsync (path *c* in Figure 5) ($\beta = -0.36$; $t = -2.04$, $p = 0.0508$); importantly, after controlling for the effect of motor planning and execution time (start of movement and value of max speed), the effect of AQ communication on Grabsync increased ($\beta = -0.38$; $t = -2.33$, $p < 0.05$) (path *c'* in Figure 5). Note that *c'* was higher than *c* due to the negative correlation between the two mediators. In the indirect path, we found a significant effect of AQ communication on time of start of movement ($\beta = -0.44$; $t = -2.62$, $p < 0.05$) (*a* in Figure 5), a significant effect of time of start of movement on value of max speed ($\beta = -0.51$; $t = -2.72$, $p < 0.05$) (*d* in Figure 5) and a significant effect of value of max speed on Grabsync ($\beta = -0.63$; $t = -3.74$, $p < 0.001$) (*b* in Figure 5). All other paths were not significant.

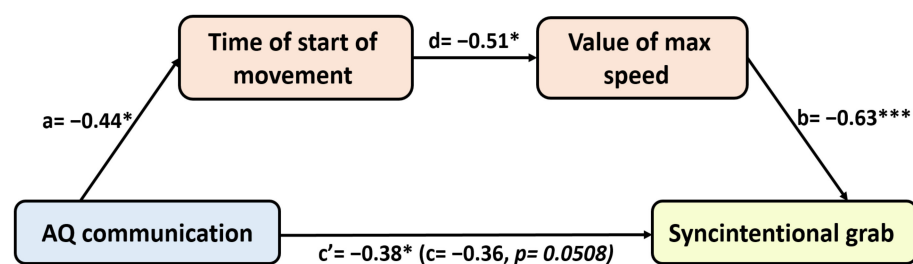


Figure 5. Motor planning and execution (as measured by time of start of movement and value of max speed; marked in red) mediates the link between AQ communication (marked in blue) and intentional synchrony form (Grabsync; marked in yellow). The displayed values are standardized regression coefficients (β s). * $p < 0.05$; *** $p < 0.001$.

The results indicate that the multiple mediation effects of time of start of movement and value of max speed on the relationship between AQ communication and intentional synchrony form (Grabsync) were significant ($B = -0.14$, 95% CI = -0.32 to -0.02).

An additional mediation analysis was conducted to examine whether the effect of AQ communication on Pinchsync, which served as a different form of interactional synchrony, was also mediated by the typical pattern of motor planning and execution. We found a significant direct effect of AQ communication on Pinchsync (*c* in Figure 6) ($\beta = -0.51$; $t = -3.14$, $p < 0.01$), but, similar to the previous results, the effect of AQ communication on Pinchsync increased after controlling motor measurements ($\beta = -0.55$; $t = -3.36$, $p < 0.01$) (*c'* in Figure 6). As mentioned above, *c'* was higher than *c* due to the negative correlation between the two mediators. In the indirect path, we found a significant effect of AQ communication on time of start of movement ($\beta = -0.44$; $t = -2.62$, $p < 0.05$) (*a* in Figure 6), a significant effect of time of start of movement on value of max speed ($\beta = -0.51$; $t = -2.72$, $p < 0.05$) (*d* in Figure 6) and a significant effect of value of max speed on Pinchsync ($\beta = -0.47$; $t = -2.79$, $p < 0.01$) (*b* in Figure 6). All other paths were not significant.

Similar to previous findings, the results indicate that the multiple mediation effects of both measurements of motor planning and execution (i.e., time of start of movement and max speed) on the relationship between AQ communication and intentional synchrony form (Pinchsync) were significant ($B = -0.10$, 95% CI = -0.26 to -0.007).

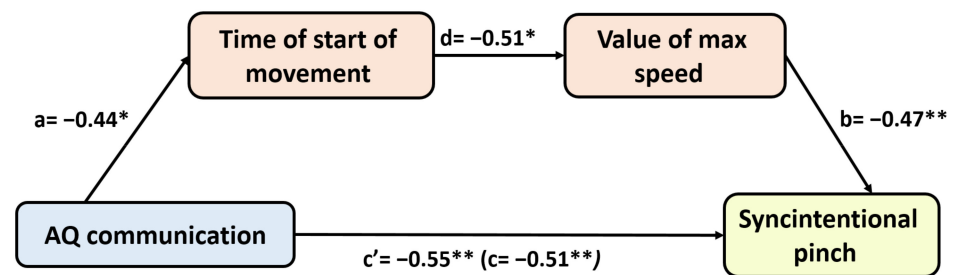


Figure 6. Motor planning and execution (as measured by time of start of movement and value of max speed; marked in red) mediates the link between AQ communication (marked in blue) and intentional synchrony form (Pinchsync; marked in yellow). The displayed values are standardized regression coefficients ((β) s). * $p < 0.05$; ** $p < 0.01$.

5. Discussion

ASD is characterized by social cognition deficits [18] and fundamental deficits in motor functioning [5]. Interactional synchrony is considered to have a crucial role in social interaction [10], since it is believed to operate as a form of social glue that fosters connectedness and affiliation [8]. Although previous studies indicated that individuals with ASD show aberrant performance in tasks that involve interactional synchrony [6,23], the possibility that motor abnormalities in ASD may contribute to their deficits in interactional synchrony has thus far received little research attention. The aim of the current study was to assess the association among autistic traits, interactional synchrony and motor deficits. In accordance with our initial hypothesis, the effect of the autistic traits of communication on interactional synchrony (as measured by synchrony in the form of the hand) was found to be mediated by typical patterns of motor functions (i.e., lower initial starting time and higher max speed). In other words, as the autistic traits in communication are higher, the formation of a motor plan is faster (as measured by the time of onset of the movement), and the preformed movement is also faster (as measured by the maximum speed reached). However, it appears that this typical pattern of faster planning and performance leads to a reduced ability to synchronize with others.

As discussed above, interactional synchrony plays a crucial role in beneficial consequences of social interactions. In accordance with the literature, our findings demonstrate that individuals with higher autistic traits of communication show more aberrant forms of interactional synchrony [6,23,26]. Interestingly, the communication subscale was the only subscale that was found to be negatively associated with interactional synchrony. These findings are consistent with a previous study that found that the AQ communication subscale is associated with different kinematic patterns in actions with social and non-social intentions. It demonstrated that people with better communication skills (i.e., lower AQ communication scores) displayed greater social kinematic differences than those with lower communication skills (i.e., higher AQ communication scores) [59].

Furthermore, the current study is the first, to our knowledge, to examine the link between autistic traits and gestures/form of hand movement. Utilizing the Leap Motion Device, the current study allowed for assessing simultaneous free 3D interactional synchrony movement of two participants, while previous studies evaluated one dimension (1D) [6,9] or 2D [60]. The first stage of motor execution is motor planning. Before performing a motor action such as a reaching movement, a movement plan needs to be developed. Findings related to motor planning in ASD are mixed [35]. On simple tasks, children with ASD and TD perform similarly [36]. However, on complex tasks, adults with ASD showed lower performance in motor functions than TD controls [37,38]. Our findings disconfirm the hypothesis of deficit in motor planning and execution in participants with many autistic traits (i.e., longer starting time), but rather show that individuals with high communication traits showed typical patterns of motor planning and execution of short reaction time, and this is associated with faster movement (i.e., higher max speed). Note that the proportion of students who study exact sciences in the higher autistic traits group tended to be higher

than the proportion of students who study exact sciences in the low autistic trait group. This is in accordance with previous studies in which students who study exact sciences showed higher autistic traits than students who study social sciences [53]. It is therefore reasonable to suggest that students who have higher autistic traits tend to study exact sciences, are better in goal directed behavior tasks and, therefore, performed better in this task.

As noted above, this is the first study to directly examine the link among motor planning and execution, interactional synchrony and autistic traits. Brezis et al. (2017) examined the connection between motor performance and co-confident motion in the mirror game task [9]. In this task, participants are asked to lead, follow or move in joint improvisation. ASD participants showed impaired motor functioning in a general motor skills test (PANESS) with slower velocity. Within the mirror game task, ASD and TD participants displayed different patterns of motion velocity. ASD participants were slower than TD participants in following rounds and marginally faster than TD participants in leading and joint improvisation rounds. When examining the connection between motor performance and co-confident motion (intervals of synchronized movement), general motor skills were found to be predictive of co-confident motion in the ASD group. To the best of our knowledge, the current study is the first to suggest motor planning and execution as a mediator. We found that part of the association between high autistic traits of communication and aberrant forms of interactional synchrony is explained by typical motor planning and execution patterns. In other words, as the autistic traits of communication are higher, the time that it takes to start the movement is shorter and the value of the max speed is higher, but the form of interactional synchrony is more aberrant. Notably, the current study included a sample which is not diagnosed with ASD, and therefore the results are limited. However, given the variation of the autistic traits across the general population [48], we expect these findings to be more robust in the ASD group.

However, the fact that social cognition and motor functioning have been associated with atypicalities in the function of the dopaminergic neurotransmitter system [61–63] highlights the possibility of underlying biological mechanisms of the dopaminergic system that explain the mediation of motor planning and execution between autistic traits of communication and interactional synchrony. Future research should examine the role of dopamine in linking motor planning and execution and interactional synchrony in individuals with ASD. As noted above, the dopaminergic system is a factor in modulating these two distinct functions [45]; we therefore call for future studies to examine the role of dopamine in linking motor planning and interpersonal synchrony in individuals with high autistic traits.

Several limitations of this study should be considered. First, our study had a relatively small sample size and did not add individuals diagnosed with ASD. Second, the findings are restricted only to hand-finger movements within a specified limited zone. The motor interaction that was examined in the study might not reflect daily interactions in real-life. Third, we did not rule out the possibility that the research assistant's motions were different across different participants. In this context, it is important to note that, although the research assistant was not blind to the aims of the research, she was blind to the level of AQ traits of each participant. Fourth, although the novel task provides data about the form similarity in more than one dimension, the limitation of using this task is the difficulty of performing a comparison of the findings with previous studies. Finally, since ASD represents cognitive deficits [64], we call for future studies to investigate the impact of cognitive functions on the association between motor functions and interactional synchrony.

However, to our knowledge, the current study is the first evidence of the possibility that typical patterns of motor function in ASD may contribute to their difficulties in synchrony motions with others. However, these findings should be regarded cautiously until they have been replicated in a larger sample.

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Appendix A

Correlations between AQ communication subscale, intentional synchrony and motor planning and execution measurements.

Table A1. Correlations between autistic traits (AQ) subscales and intentional synchrony measurements.

	Intentional Synchrony				AQ		
	1	2	3	4	5	6	7
Intentional synchrony							
1. Grabsync	–						
2. Pinchsync	0.81 ***	–					
AQ scores							
3. Social skill	–0.09	–0.10	–				
4. Attention switching	–0.14	–0.11	0.21	–			
5. Attention to details	–0.25	–0.34	–0.18	0.15	–		
6. Communication	–0.36						
7. Imagination	(<i>p</i> = 0.051)	–0.51 **	0.62 ***	0.21	0.10	–	
8. Total AQ	0.005	–0.10	0.39 *	–0.06	0.11	0.27	–
	–0.29	–0.40 *	0.67 ***	0.55 **	0.34	0.77 ***	0.56 **

Note. AQ = Autism Spectrum Quotient; * *p* < 0.05; ** *p* < 0.01; *** *p* < 0.001.

Table A2. Correlations between AQ subscales and motor planning and execution measurements.

	Motor Planning and Execution				AQ			
	1	2	3	4	5	6	7	8
Motor planning and execution								
1. Time of start of movement	–							
2. Time of max speed	0.43 *	–						
3. Value of max speed	–0.49 **	–0.17	–					
AQ scores								
4. Social skill	–0.14	0.14	0.12	–				
5. Attention switching	0.03	0.16	0.18	0.21	–			
6. Attention to details	0.02	0.25	0.24	–0.18	0.15	–		
7. Communication	–0.44 *	0.05	0.19	0.62 ***	0.21	0.10	–	
8. Imagination	–0.115	0.19	–0.05	0.39 *	–0.06	0.11	0.27	–
9. Total AQ	–0.18	0.29	0.19	0.67 ***	0.55 **	0.34	0.77 ***	0.56 **

Note. AQ = Autism Spectrum Quotient; * *p* < 0.05; ** *p* < 0.01; *** *p* < 0.001.

Table A3. Correlations between intentional synchrony and motor planning and execution.

	Intentional Synchrony		Motor Planning and Execution		
	1	2	3	4	5
Intentional synchrony					
1. Grabsync	–				
2. Pinchsync	0.81 ***	–			
Motor planning and execution					
3. Time of start of movement	0.16	0.17	–		
4. Time of max speed	–0.08	–0.07	0.43 *	–	
5. Value of max speed	–0.54 **	–0.43 *	–0.50 **	–0.17	–

Note. AQ = Autism Spectrum Quotient; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

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