Micro-movement as an objective measure to assess autism spectrum disorder

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Abstract

The assessment of the Autism Spectrum Disorder (ASD) has always focused on the observational analysis of behavior, primarily aiming to detect the presence of some behaviors considered typical of the disorder. However, autism is often characterized by motor abnormalities as well. This paper presents a pilot study with the aim to assess the preliminary capability of a software for micro-movement analysis to detect typical characteristics of movement in subjects with ASD. Therefore, the software has been tested on a small sample of ASD subjects and the results have been compared to those of a group of subjects with typical development (TD). The results showed that it is possible to observe some differences between the groups in relation to some parameters of effectiveness, linearity, and average speed of trajectories.

Keywords: Autism; Micro-Movement; Sensory-Motor Impairment; Motion Trajectory Analysis

1. Introduction

Autism is a neurodevelopmental disorder, a behavioral syndrome characterized by serious organizational difficulties of thought and of the main functions that regulate human adaptation. It is considered a func-

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tional disorder or executive function disorder which involves a permanent general disability within three main areas: qualitative impairment of social interaction, qualitative impairment of communication, and the presence of restricted behaviors, interests, and activities, which are repetitive and stereotyped. In addition to the aforementioned triad of impairments, characteristics of individuals with ASD include also numerous motor dysfunctions (Damasio & Maurer, 1978; Donnellan, Hill, & Leary, 1995, 2013; Maurer & Damasio, 1982). In particular, they may have delayed development of the fundamental movement skills, which results in difficulties in organizing a series of movements in a fluid and coordinated manner. They also show the persistence of "primitive" reflexes that normally disappear a few weeks after their birth (Minderaa, Volkmar, Hansen, Harcherik, Akkerhuis, & Cohen, 1985; Reed, 2007) and alterations of muscle tone – they are often affected by hypotonia.

Being able to perform functional motor actions is not enough to cope with the human everyday environment. Instead, it is necessary to plan and sequence a series of movements and to coordinate their single aim in more complex actions for a superordinate final purpose. A voluntary action stems from a synergic process that involves different cortical areas, each of which contributes to determining the best ways to adapt to the surrounding environment. In an autistic subject, the brain areas that govern processes and organization of the movement work in an anomalous way (Mosconi, Mohanty, Greene, Cook, Vaillancourt, & Sweeney, 2015). In general, research in ASD considers movement as a form of efferent motor output, with a unidirectional flow from the central nervous system (CSN) to the peripheral nervous system (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Gowen, Stanley, & Miall, 2008; Jansiewicz, Goldberg, Newschaffer, Denckla, Landa, & Mostofsky, 2006; Jones & Prior, 1985; Minshew, Sung, Jones, & Furman, 2004; Mostofsky, Dubey, Jerath, Jansiewicz, Goldberg, & Denckla, 2006; Noterdaeme, Mildenberger, Minow, & Amorosa, 2002; Rinehart, Bradshaw, Brereton, & Tonge 2001; Teitelbaum, Teitelbaum, Fryman, & Maurer, 2002; Williams, Whiten, Suddendorf, & Perrett, 2001). Movement should also be interpreted as the result of reafferent feedback from the environment, whose information is modulated from the periphery to the CSN. At this level, movements play a fundamental role in the intentional control of our actions and decisions.

We refer to "micro-movements" as re-afferent feedbacks that lead to specific stochastic patterns of movement fluctuations over time, which contribute to the regulation, coordination, and control of the action, in correspondence with a gradient of variability that goes from levels of autonomy to voluntary control (Torres, 2011). At the two extremes of this gradient, voluntary behavioral variations would have different stochastic signatures as compared to the behavioral variability of involuntary movements. Spontaneous movements and reflexes exist embedded in natural sequences of movement and take rhythmic cadences which are thought to be socially influenced before perception has fully matured (Condon & Sander, 1974). In the ASD, the evolution of voluntary movement is impaired, and, in particular, a characteristic inconsistency between the intention and the final output may be observed (Robledo, Donnellan, & Strandt-Conroy, 2012). While the regular development of movements is associated with an innate ability to easily perform different series of movements depending on the context, subjects with ASD seem to be deficient in this type of competence (Torres, 2011). Therefore, it is expected to find some anomalies of the micro-movement during the execution of voluntary actions, where the feedback from the surrounding environment plays a decisive role in programming the action.

In order to fully achieve voluntary control and full regulation of motor output, each biological system needs to receive a real-time minimum amount of afferent sensory feedback from the outside (Torres, Brincker, Isenhower, Yanovich, Stigler, Nurnberger Jr., Metaxas, & José, 2013). The feedback we receive from the environment can produce the same sensory input even if they have different origins. This ambiguity may bring problems of interpretation that can only be solved by means of a prior belief about what generated our sensory stimulus. According to the Friston's predictive coding theory (2005) top-down predictions are produced by the higher brain areas. Then, top-down predictions meet the bottom-up sensory signals, from the peripheral nervous system, allowing the right integration between prediction and sensory stimulus. A discrepancy in this process would generate a prediction error. Some dysregulated systems may be more influenced by one of this information, thus preventing the correct processes of prediction, processing, and planning of the action.

ASD subjects seem to fail to mitigate the bottom-up influence that would produce an excessively accurate interpretation of the surrounding reality through the filter of the senses: we could consider them as 'slaves to their senses'. Some studies about functional magnetic resonance imaging (fMRI) have demonstrated that the ASD population has a greater activity of the visual areas to the detriment of the prefrontal cortex during visuo-spatial tasks, and the higher cortical areas are essential for prediction error processes (Friston, 2005). Such data would suggest the presence of a cortical dysregulation and would point out part of the anomalies in behavior and movement of these subjects.

A possible interpretation is that this excessive sensory precision may be induced by a failure in sensory attenuation and by insensibility to the context. This failure would thus hinder the activation of the processes for a proper interpretation of reality, and prevent a fluid action planning, which requires a constant encoding of the stimuli that the organism receives, in order to coherently carry out planned actions in the surrounding environment. Therefore, the low effectiveness of the top-down predictive system in ASD subjects can result from less attention to their environments. These subjects are, in fact, particularly sensitive to some rehabilitation techniques that manipulate environment and responses, in terms of reinforcements and punishment. The aim is to bring these patients back into their context and make them more responsive to the environmental feedbacks that normally direct the action (Ponticorvo, Rega, & Miglino, 2018).

From a neurobiological point of view, programming, coordination, and regulation of movements are regulated by information through afferent somatic fibers (GSA). Part of this information flows through the so-called conscious 'proprioceptive' channels and reaches the neocortex through the thalamus, while other types of information flow through unconscious proprioceptive channels targeting the cerebellum, striatum and limbic systems (O'Rahilly & Müller, 1983).

Normally, a balanced and flexible exchange between these reafferent forms of feedback facilitates the central regulation, the anticipation of problems, and an effective control of motor output and its effects. In ASD some anomalies subvert this balance. The process results in difficulties with the interpretation of the sensory feedback from the environment, and therefore with a coherent action planning in relation to the information received from the outside. The resulting process is supposed to have typical features, which could allow us to recognize the anomaly earlier and trace its evolutionary path. In order to correctly assess these characteristics, it is necessary to analyze the behavior in a more sophisticated manner.

By studying behavior from a merely subjective perspective, referring to purely psychological theories and hypotheses, many fundamental elements that are intrinsically present in natural behaviors do get lost. Some behavioral movements have a clear purpose and can be readily identified through conscious observation. Yet, a large majority of human actions can go undetected. These movements occur too quickly, within frequencies and timescales, and elude conscious observation. However, contemporary technology enables us to capture these movements with extreme accuracy. Technology makes movement measurable, and its quantification can bring studies on autism to a higher and more rigorous standard. Moreover, the use of digital assessment tools can have a great impact on the clinical evaluation processes, especially for the ASD population. Proposing simplified and more easily controlled models of reality, they can be beneficial to obtain results which can overcome the limits of mere observational evaluation, focusing more on the construct of interest, and being less dependent on environmental variability (Ponticorvo, Di Fuccio, Ferrara, Rega, & Miglino, 2019).

Taking all this into consideration, our main goal is to create a digital assessment tool that can give us an objective measure of an individual's motor activity, sectioning it into micro-movements. For this purpose, we have developed a software for detecting micro-movements. The present pilot study describes the preliminary assessment of this tool on a small sample of autistic subjects, compared with as many subjects with typical development.

The results of the analysis of micro-movements during a task involving the matching of identical pictures will be illustrated below, within contexts where the increasing complexity is due to the addition of major distractors and details.

2. Methods

Participants were eight subjects, 4 ASD and 4 TD, (aged 5,5 +/- 0,32). Both groups were composed of 2 females and 2 males. The 4 ASD subjects were diagnosed with autism spectrum disorder by qualified doctors and professionals in the sector who have no affiliation with our laboratory or our research, the results of the ADOS-2 (Lord, Rutter, DiLavore, Risi, Gotham, & Bishop, 2012) were all within the spectrum range. The ASD subjects follow psychomotor and speech therapy treatment at the Neapolisanit S.R.L. center, no specific comorbidity has been reported.

All participants were administered by Raven's Progressive matrices in order to obtain the IQ scores for each participant and none of them have shown mental retardation.

Subsequently, each participant performed a brief task with an estimated average duration of 10 min, during which the user had to select and drag the images to the bottom of the screen and position them on the corresponding image at the top, depending on the task delivery. A Huawei MediaPad T3 10 tablet has been used for the task.

The task was a classic *Matching task*, which normally involves the association of equal stimuli in the presence of distractors. The matching task proposed to our subjects reproduced the first 10 items of Leiter-3 matching task (Roid, Miller, & Pomplun, 2013). The Leiter-3 is a test widely used in the field of autism for the non-verbal evaluation of intellectual and cognitive abilities, providing an IQ value.

The software was developed in Unity and consists in the presentation a sequence of 10 scenes taken by the Leiter-3. The progression between the scenes can be automatic, when the subject succesfully reach the end of a task, or it can be triggered by an external action of the examiner when the subject is unable to complete the task.

The task consists in pairing identical images. Each scene is composed of a maximum of 3 images at the bottom of the screen, which can be moved from one point to another on the screen by dragging, and a maximum of 6 fixed images placed at the top of the screen. We call the images at the top "placeholders" and these are programmed to capture the images moved by the subjects, when they are dropped above them. The placeholders for each task range from a minimum of 2 to a maximum of 6 and include distractor images. All images reproduce geometric figures of different shapes and colors. In the more complex scenes these figures are characterized by small details that differentiate them, as shown in Figure 1. The task is characterized by a growing difficulty given by the progressive increase in the number of distracting stimuli and the distinctive details of the images. The ascending levels of difficulty requires increasing levels of attention and decision-making. During the performance, the software recorded the presence of the stimuli and, simultaneously, the movement coordinates resulting from the dragging movement of the images from one point to another of the screen.

The coordinates were recorded over time, taking into account the time dimension in milliseconds, in order to analyze the parameters of our interest. The recorded space-time coordinates allowed to build movement's trajectories and to analyze them as a function of some parameters to evaluate their effectiveness, linearity and average speed. The analyses were conducted using the Rstudio data analysis software and the *traj* package was used for trajectory analysis (Sylvestre, McCusker, Cole, Regeasse, Belzile, & Abrahamowicz, 2006; Leffondree, Abrahamowicz, Regeasse, Hawker, Badley, McCusker, & Belzile 2004).

The analysis concerned the following parameters:

Straightness (STH) is the measure of the effectiveness of a trajectory calculated on the time series produced by the coordinates of the moving image in time, during the task execution. It is given by the ratio between the distance between two points and the length of the trajectory. The straightness index is a number ranging from 0 to 1, where 1 indicates a straight line.

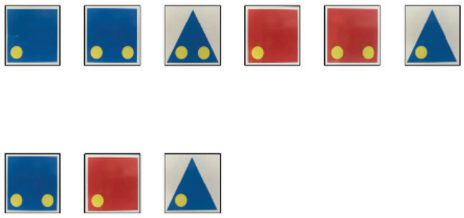

Figure 1. Example of complex scenes

Directional Change (DC), measures the amount of changes in the direction of the moving image over time. DC is defined for each pair of steps and may be used as an index of nonlinearity.

Furthermore, we calculated *linear speed* and *acceleration* along the trajectory of the moving image. Before this calculation every trajectory was smoothed. Many trajectories will suffer from noise which will bias the results of some analyses. The smoothing process reduces high frequency noise while preserving the shape of the trajectory, by applying a Savitzky-Golay smoothing filter.

A further observed measure is related to the strategies used to perform the task, which each subject has implemented.

We observed the sequences of actions implemented during each task and then, we analyzed the variability of the strategies implemented.

Taking into account that for each task, the objects which they interacted with were maximum 3; the possible sequences were 6. We have analyzed the repetitiveness of these sequences between and within the groups. We used the hamming distance measurement to compare the sequences.

3. Results

3.1 Trajectory analysis

The results obtained from the analysis of the recorded trajectories showed some differences between the groups in terms of trajectory effectiveness (STH), movement direction variability (DC), task speed and task execution strategies. This section will explain the obtained data in detail.

The STH levels, recorded for the two groups, show some differences, more specifically the control group (TD), has maintained higher STH levels whose parameter fluctuates between values ranging from 0 to 1. The data indicate an average STH value for the TDs of 0.479 with a SD of 0,147 while for the ASD group we record an average value of 0.382 and SD of 0,114. The difference observed is slight but remains constant during different tasks, as shown in Figure 2. The STH parameter reflects the trajectory effectiveness, it is given by the ratio between the distance traveled and the distance between the starting point and the arrival point of a specific, finite and determined movement. So, in order to obtain a valid measurement of this parameter, all the finite trajectories recorded singly have been analyzed, and each STH value has been calculated.

The ASD group maintains over time more effective trajectories. Furthermore, the STH values showed a decreasing trend in both groups, showing that, the effectiveness of the trajectories decreased, as long as the difficulty of the task increased.

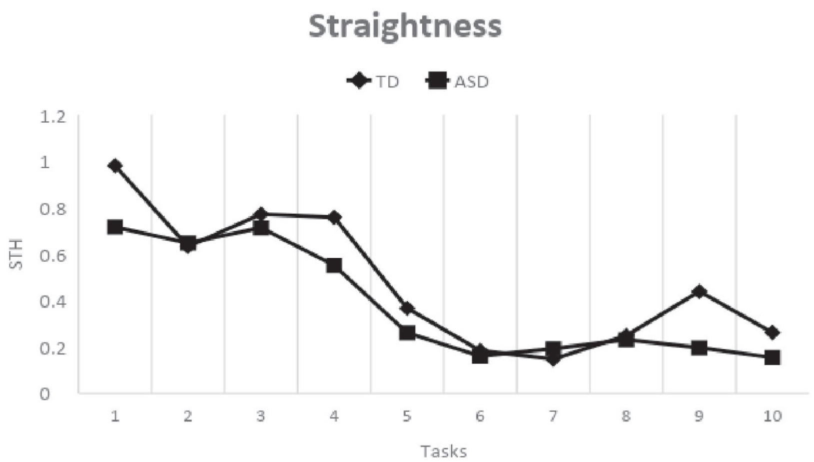

Figure 2. Average STH values for each task

Concerning DC values, which indicate the movement directions variability, we observed higher values in the TD group with 3.32 +/– 0,33, compared to 2.86 +/– 1,43 for the ASD group.

Through this parameter we observed the direction variability during each single task. This parameter was recorded using the complete paths implemented from the beginning to the end of each individual task. The trajectories were observed in their integrity for each task. This variability was higher for almost all tasks in the TD group, except in two cases (Figure 3).

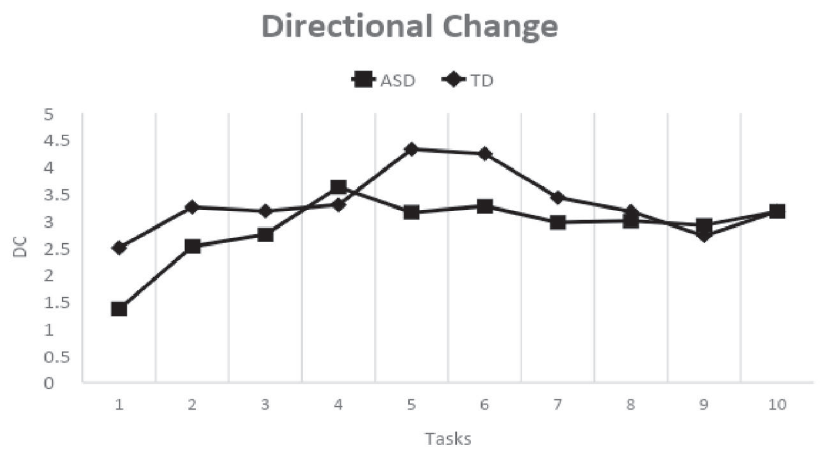

Figure 3. Average DC values for each task

MeanSpeed parameter has been recorded by analyzing the movements implemented during each task, excluding the latency times between different movements. *MeanSpeed* does not refer to the speed with which subjects perform the task. We analyzed the speed of the movement in a pure way, in order to avoid the purely cognitive effects of action planning.

Group averages for each task are shown in Figure 4. The average speed in the ASD group draws a line characterized by a slightly decreasing trend, conversely, the TD group's speed value, shows a clearly increasing trend.

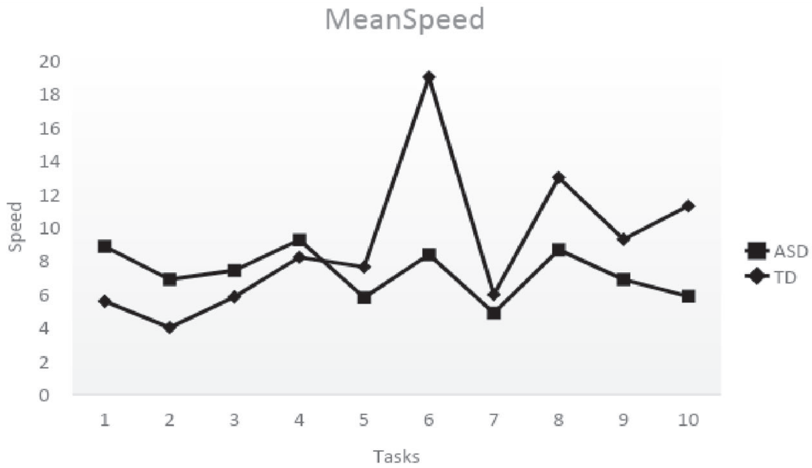

Figure 4. Average speed of movement during tasks

3.2 Strategy analysis

During the task, the software constantly kept track of the position of the images on the screen, recording the items selected on each occasion.

These data allowed us to observe the ways in which the subjects chose to interact with each task, the images they selected and hence, the interaction strategy implemented.

During the tasks, the subjects could choose to interact with a maximum of 3 images per task, these images were positioned at the bottom right of the screen, placed at a specific distance from each other, as shown in the Figure 5. The distance between the images and their position remains fixed for each task.

In order to analyze these data we have considered the interaction patterns as strings and we have compared them using the humming distance measure. We have defined as conventional string the sequence A-B-C, this string corresponds to the order in which the items are presented, from the most extreme on the right, to the last on the left and corresponds with the most used string. In fact, this conven-

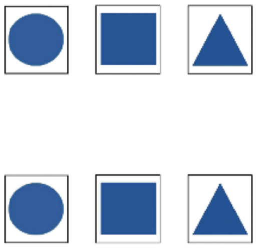

Figure 5. Example of a simple matching task

tional string has been chosen with a percentage of 55%. A more detailed analysis allowed to observe that the 77% of this preference is explained by the choices of ASD subjects.

The *strategic variability*, thus calculated, reaches an average value of 5.25 for the ASD group and 20.25 for the TD group.

4. Discussion

The present is a pilot study conducted with the aim of observing the effectiveness of the software in detecting movement patterns typical of autism. Given the small dimension of the sample size, the reported results have not been interpreted in lights of specific statistical hypothesis and we do not claim any particular meaning at population level. In this preliminary phase we have presented the results in a purely descriptive way and we will discuss the average of the values associated with the parameters considered. On a larger sample we expect to be able to statistically confirm our results.

The preliminary results show the differences in the trajectories of movement between the groups examined. In fact, the results obtained from the analysis of the software data allow us to observe that the trajectories of ASD subjects are less effective and at the same time more repetitive.

We propose to interpret the highest DC values for the TD group, as the "biometric" demonstration of the highest *strategic variability* that has been observed in this group.

With respect to the average velocity values shown by the two groups, we observed a decreasing velocity trend in the ASD group, conversely, an increasing trend was observed in the TD group.

Although we could have expected that the speed was reduced as the task became more difficult, we noticed that for subjects with typical development this does not occur. So, despite the task became more complex, these subjects shown had better performance in terms of time, probably, because they learned the strategy and gradually became more performing.

In the ASD group this did not occur, probably because, as explained by Friston in his predictive coding theory, the ASD subjects are hyper-sensitive to sensory inputs and poorly conditioned by their prior beliefs (Friston, 2005). This results in impaired ability to learn from the context and plan actions in a dynamic and coherent way with the new information from the environment.

Furthermore, the repetitive performance pattern, observed in ASD group, could be due to their maladaptive habit to start movement before having planned their actions. If this is true, this behavior could be explained as an unconscious attempt to control the environment, confirming our initial hypotheses inspired by Friston's free energy principle. In fact, Friston claimed that the movement would be a strategy to control the enormous amount of sensory input that comes from the environment and to soothe the need to infer their causality (Lawson, Rees, & Friston, 2014).

Moreover, his interpretation also allows the results relating to the STH parameter to be explained. In fact, an ineffective planning process, such as the one just described for the ASD group, would result in less effective trajectories of movement and so, in low levels of STH.

5. Conclusions

The proposed study confirms some of our initial hypotheses, showing some interesting differences between the movement patterns of the two groups examined.

The results of the data analysis obtained from the software allowed us to observe some characteristics, presumably typical of the ASD. The results of the study clearly refer to a preliminary sample, but the parameters taken into account highlighted some movement patterns which, if confirmed on a larger sample, could give us new indications concerning the autistic spectrum disorder and it could allow make the assessment and rehabilitation processes more accurate.

The theory of predictive coding, proposed by Friston, seems to be supported by the data obtained and if these results will be confirmed on a larger sample, it could suggest a new way for the interpretation of the autistic symptomatology, allowing to investigate more deeply this disorder and its more specific characteristics.

Our future purpose is to extend the sample to more subject with different IQ levels. Understanding the skeleton of the anomaly and analyzing it in detail, during different types of tasks and, thus, different levels of cognitive processing, it becomes possible to imagine new rehabilitation strategies, and customize them in relation to the subject characteristics.

One of the limits is certainly related to the impossibility to exclude an effect of sustained attention on the results, in particular on MeanSpeed value. This limit can be solved by inserting more tasks of different types and measuring the speed variations within the different tasks, in order to verify if the speed changes depending on the *time* variable or on the *task complexity* variable. In addition, a further control of the information can be guaranteed through a simultaneous analysis of eye movements.

We imagine that one of the interesting future scenarios may concern the use of an eye-tracker device designed to detect the coordinates of eye movement during the performance. The coordinates of the movement on the hand, together with those of the eyes can provide us with important data relating to the oculo-manual coordination patterns, typically impaired in subjects with ASD, as well as greater control of the attention variable. The difficulties of oculo-manual coordination are among the main manifestations of ASD. An instrument conceived in this way will be able to improve the assessment processes by providing a new implicit measure of the disorder and, at the same time, allowing the rehabilitative approach aimed at the reorganization of the coordination schemes, which, in this way, can be calibrated to the needs of each subject.

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