ORIGINAL RESEARCH

Dynamical analysis of the interaction between object location and hand use in a midline crossing task in children with trisomy 21

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Abstract

Objective: The aim of the study was to analyze the influence of spatial constraints on the hand use in children with trisomy 21.

Methods: Participants were 31 children with trisomy (13.35 ± 2.78 years old, 18 girls) (T21) and 38 children with typical development (8.62 ± .79 years old, 22 girls) (TD), with similar APGAR scores at birth (1 mn and 5 mn), but with significantly different mental age in Goodenough test. Children grasped seven colored Styrofoam balls in a semi-circumference arraying; in a pseudorandom condition (R) and in a scaling condition (increasing sequence [IS]- from left to right hemispace; decreasing sequence [DS]- from right to left hemispace).

Results: In the R, TD displayed a significantly greater frequency of midline crossing than T21, as in the DS; but not in the IS condition. T21 showed significantly larger hysteresis in the left hemispace, as well as in the midline location, but not in the right hemispace. In R, IS and DS, no significant differences were observed between TD and T21 in the frequency of left-hand use.

Conclusion: Spatial constraints highly determined T21 hand-use, as clearly expressed in the pattern of midline crossing and of hysteresis. In T21, the scaling procedure permitted the detection of patterns of interaction among spatial and intrinsic constraints, that the traditional R procedure would not. This perceptual-motor pattern of behavior should be considered as criteria in the planning of perceptual-motor intervention for children with T21. We propose the "task constraints attunement hypothesis", suggesting that T21 children (and, probably others with developmental problems) reveal more left-handedness and less asymmetry because they are compelled to use the hand in accordance with spatial constraints.

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Introduction

Trisomy 21 is the most common form of genetic mental retardation.[1] Left- hand use has been associated with developmental problems, probably with a genetic origin,[2] but the impact of task and environmental constraints is recognized.[3] Cornish et al[4] assessed hand preference and hand skill in 20 children with T21, and of 20 who had TD, and found no difference in either the proportion of left-handedness nor consistency of handedness. Devenny et al[5] tested 31 adults with T21 and found that 48% of participants were right-handed, 13% left-handed and 39% mixed-handed. A summed score of laterality did not correlate to intelligence quotient (IQ). Vlachos et al[6] classified children with T21 (7-9-year-olds) and teenagers with T21 (13-15-year-olds, comparing them to typically developing persons, and found that mixed-handedness were more frequent among individuals with T21. Carlier et al[2] found that persons with T21 (8-34-year-old) were more left-handers, less right-oriented and had higher inconsistent laterality compared to TD children (8.26 ± .05 years old); T21 also did not

display more midline crossing inhibition than the TD group. Similar results were found by Gérard-Desplanche et al,[7] and Bahteja et al.[8] However, most of these authors also state that there is no clear evidence of predominance of left-handedness in T21.[2]

Methodologically, results are normally collected from questionnaires [9] and/or from tasks where trials with hand use are made used for various spatial locations, that are presented in a random sequence.[10] However, and alternately, for tests involving grasping an object we can apply a scaling procedure, where the spatial locations are presented sequentially in one direction (e.g., from the left to the right), and then in the opposite direction (from right to left).[11–14] Rostoft et al[11] used this scaling procedure in a ball-catching task with 4-year-old children, and they found a phenomenon typical in dynamical systems, a catastrophe flag called hysteresis. A dynamical system is one that evolves over time, in such a way that its present state always depends on previous states; allowing the self-organizing capacity of the (perceptual-motor) system. When an appropriate control parameter (such as spatial location of the object to be grasped) is scaled in different directions (from left to right hemispace and from right to left hemispace), what happens is that shifts of the hand used (left or right) take place for the same object's location, enabling the identification of so-called hysteresis areas; which means that for different initial conditions different patterns of behavior will emerge. In our case, hysteresis is the tendency for the child's motor response at one endpoint of his/her hemispace (e.g., grasping the ball with the left hand when it is at the child leftist side) to persist across the ordered sequence of locations where the object to be grasped presents itself towards the other hemispace endpoint. In this case, the tendency to persist in grasping the ball with the left hand even if the ball to be grasped is in his/her right hemispace. So, the observation of hysteresis implies bi-stability in perceptual-motor action, i.e., two motor behaviors are possible for the same ball spatial-location.

Our hypothesis is that with scaling procedure we can analyze the strength of extrinsic spatial constraint in the frequency of the use of either right or left hand, which is masked in a random procedure. Additionally, the scaling procedure also allows the analysis of the influence of the same spatial condition but under different initial conditions, meaning that instead of hand use to be a consequence of motor- programming it can be a result of interaction among intrinsic and extrinsic constraints.[15]

Data collected through the scaling procedure allows non-linear analysis, more focused on the process and on phases of instability of the behavior than on the product and on the predominantly stable behavior. So, if the action of grasping an object is a dynamical process, emerging from the interaction among intrinsic constraints (e.g., T21) and extrinsic constraints (e.g. object 's spatial location), hysteresis should occur. Furthermore, if extrinsic constraints are more determinant for children with T21, a larger hysteresis would emerge from their motor responses, compared to the one observed in children with TD. Additionally, in a test like card-reaching,[10] but with a scaling protocol, it is expected that if the extrinsic constraint spatial location strongly determines which hand to use in T21 children, then, midline crossings will be fewer than those observed in children with TD.

The purpose of the present study was to explore the dynamical pattern of hysteresis in children with T21, compared to children with TD, using the scaling procedure in a task of grasping, in an experimental device similar to Carlier et al.[2]

Methods

Participants

Participants were 31 children with trisomy (13.35 ± 2.78 years old, 18 girls) (T21) and 38 children with typical development ($8.62 \pm .79$ years old, 22 girls) (TD), with similar APGAR scores at birth (1mn- $z = 1.075$, $P > .1$, r = .14; and, 5 mn- $z = .109$, $P > .1$, r = .01), but with significant differences at the Goodenough's mental age ($z = 5.865$, $P < .0001$, r = .68). None of the participants had a pronounced physical disability that could substantially influence limb preference. Each participant was tested individually. All participants were recruited from parents' associations. Participants lived with their families who gave their informed consent. Participants gave their assent. Procedures followed are in accordance with the ethical standards of the responsible national committee on human experimentation and with the Helsinki Declaration of 1975, as revised in 2000. The TD group is younger than the T21 group, but laterality in TD persons is fully developed by the age of 8 (16).

Materials and Methods

Frequency of hand-use was assessed with a variant of the card-reaching test.[10,17] Persons with T21 are slow in movement and frequently awkward; so, to facilitate reach to grasp, there was no time limit, and by verbal identification and through the presenting of a card with the correspondent color, the children grabbed colored Styrofoam balls (weight: 3 g, diameter: 6 cm), in a semi-circumference arraying (child's left side: 0°, 30°, 60°; child's midline: 90°; child's right side: 120°, 150°, 180°), at their personal space (2/3 of arm length); in a pseudorandom condition (R) and in a scaling condition. The scaling condition was composed of two series of trials each, one comprised a block of seven trials in a left-to-right direction, i.e., from left to right child hemispace (increasing sequence- IS), and the other in a right-to-left direction, i.e., from right to left child hemispace (decreasing sequence- DS), with the purpose of observing the effect of scaling the spatial location of ball location.[11] The order of the starting direction was alternated across children. Only 1 trial was set for each position in each sequence, as it is difficult for mentally disabled persons to maintain their

attention for long periods of time. The box in Bishop's original procedure, was substituted by a hole next to the body of the subject, where he/she inserted the grasped balls. The activity was presented as a game. Children were seated, in front of a table adjusted to his/her height, and at the beginning of each trial, the hands were on their thighs. Individual intelligence quotients were obtained through Harris-Goodenough drawing test.[18,19] To estimate predominance of laterality in functional hand use the van Strien's[20] laterality questionnaire was applied and lateral predominance was estimated.

Statistical Analysis

For each sequence of the scaling condition, cumulative frequency of left-hand use was estimated,[21,22] and, we have calculated a value for the amount of hysteresis interval exhibited by the order parameter (hand used) as the difference between two critical control parameter values (for both sequences, IS and DS, same location angle of the object to be grasped.[23] Shapiro-Wilk test was used to verify normal distribution of the data. Mann-Whitney (z) test was used for between-group comparisons. Effect sizes r was estimated. Spearman's coefficient of correlation (r_s) was used for association between variables. The level of significance was set at $P < .05$.

Results

Results from the questionnaire revealed no significant difference between-groups in functional daily life predominant hand use ($z = .602$, $P > .1$, r = .07) and in lateral predominance ($z = .301$, $P > .1$, r = .03) (4). No significant association was found between questionnaire results and intelligence quotient ($rs_{(67)} = -.099$, $P > .1$).[5] In frequency of left hand use, no significant differences were found between TD and T21 in the R (2.16 ± 2.81, Md = 0 and 1.84 ± 1.97, Md = 2, respectively) ($z = .077$, $P > .1$, r = .01), in the IS (1.71 ± 2.53, Md = 0 and 1.35 ± 1.88, Md = 0, respectively) ($z = .184$, $P > .1$, r = .02), and in the DS (2.16 ± 2.72, Md = 0 and 3.10 ± 2.39, Md = 4, respectively) ($z = 1.661$, $P > .1$, r = .20). In the R, TD had significantly more frequency of midline crossing (2.58 ± 1.03, Md = 3) than T21 (1.81 ± 1.30, Md = 2) ($z = 2.602$, $P < .01$, r = .31),[16] as in the DS ($z = 3.507$, $P < .0001$, r = .42; 2.63 ± 1.08, Md = 3 and 1.61 ± 1.23, Md = 2, respectively); but not in the IS ($z = 1.267$, $P > .1$, r = .15; 2.42 ± 1.18, Md = 3 and 2.10 ± 1.22, Md = 3, respectively) (Figure 1).

T21 had significantly larger intervals of hysteresis in the left hemispace (30°- $z = 2.434$, $P < .05$, r = .29; 60°- $z = 2.907$, $P < .01$, r = .35), and in the midline location (90°- $z = 2.331$, $P < .05$, r = .28), but not in the right hemispace (120°- $z = 1.020$, $P > .1$, r = .12; 150°- $z = .770$, $P > .1$, r = .09) (Figure 2).

Discussion

Overall, the findings of the present study confirm that the scaling procedure can be used with children with T21, and is very revealing with regard to their less defined intrinsic dynamics, confirmed by the broad hysteresis areas; as areas of uncertainty with respect to which attractor-left or right hand- should carry out the reach-to-grasp action. So, spatial constraints highly influenced T21 hands' use, also well-defined in the pattern of midline crossing. The fact that T21 had less midline crossing

Figure 1. Midline crossing patterns of typical development group and of trisomy 21 group, in the pseudo-random condition, increasing sequence and decreasing sequence.

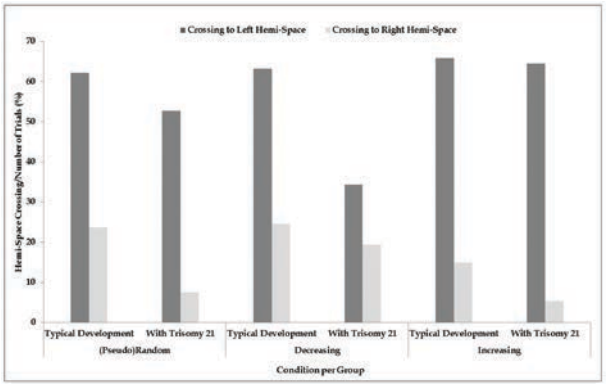
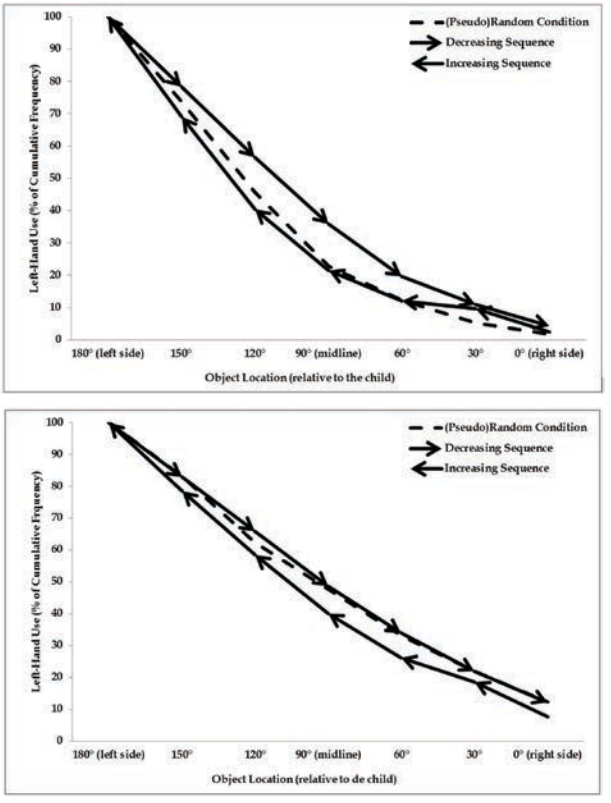


Figure 2. Hysteresis interval (increasing-decreasing sequences) of typical development group (top image) and trisomy 21 group (bottom image), based on percent cumulative frequency of left-hand along object location (control parameter), also contrasting with the calculations for pseudo-random condition.



frequency in the R condition and in DS (reinforced by a lower standard error than TD), but not in the IS, clearly shows that they were more synchronized with spatial constraints than TD. These results, particularly the absence of significant difference between T21 and TD in the IS, also reveal that the scaling procedure afforded the detection of patterns of interaction among spatial and intrinsic constraints that the traditional R procedure didn't.[11] So, instead of the "increased randomness hypothesis" which suggests that a decrease in asymmetry rather than an increase in left-handedness is characteristic of individuals with developmental disorders,[24,25] we propose the "task constraints attunement hypothesis", suggesting that T21 children (and, probably others with developmental problems) reveal more left-handedness and less asymmetry because they are compelled to use the hand in accordance with spatial constraints, and, probably, other task constraints. We propose that this informational anchoring with task constraints is a way that children with T21 have to compensate their intrinsic developmental problems, which results in those patterns of hand - use, which (we suppose) drove researchers to concepts such as mixed-handedness[6] or less right-orientation.[2] The question is not the predominance of left-hand use or being a left-hander, but the way these children find to compensate their intrinsic limitations, which is through a direct connection between ambient visual information and motor action, the object is on this side so, I use this hand.

If our hypothesis holds, the influence of spatial constraints should be considered as criteria in the planning of perceptual-motor stimulation of children with T21, because transitions between categories of action, i.e., using the left or the right hand, can be better calibrated in a self-organized and non-directive fashion. If a child with T21 shows difficulty in performing a motor task it may be because objects are not well spatially organized, or the demonstration was made in a manner that affected the compatibility stimulus-response, e.g., in a mirror mode. On the other hand, we may see the spatial organization of motor activity as a way to afford self-organization, e.g., if an object to be used as a tool is systematically presented in the midline of the child in various positions, spatial location and orientation will constraint him/her to explore hand(s) positions in order to use it, stimulating motor (and neural) plasticity.[12] It is pointless to observe that nonlinear dynamics offers an explanation of the bi-stability of hand use observed in this study and that a theoretical programming information positioning is less adjusted to the patterns of behavior observed; meaning that intervention with children, particularly those the ones with developmental problems, cannot be focused predominantly on their limitations (internal mechanisms) but on the affordances that emerge from the interaction between their own constraints and the task constraints, that are defined by us, teachers and therapists.

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