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Specific Grasp Characteristics of Children With Trisomy 21

ABSTRACT: *Children with trisomy 21 display atypical manual skills that change to some extent during development. We examined grasp characteristics and their development in 35 children with trisomy 21, aged 4–18 years, who performed simple manual tasks (two manual tasks of the Movement Assessment Battery for Children, and grasping of five wooden blocks whose size was determined by their hand size). The age-matched comparison group included 35 typically developing children. Children with trisomy 21 were found to use fewer fingers than children in the comparison group in each task. They also used specific grasps and tended to extend fingers that were not involved in the grip. While some specific grasp characteristics of children with trisomy 21 decreased with age, other did not, and remained present throughout development. The perceptual-motor development of children with trisomy 21 should be analyzed in terms of atypical development rather than developmental delay. © 2010 Wiley Periodicals, Inc.* Dev Psychobiol

Keywords: *Down syndrome; trisomy 21; sensorimotor control; grasping; development*

INTRODUCTION

Full trisomy 21 (T21) is the most common form of genetic mental deficiency. It is often referred to as "Down syndrome," although this is not the most appropriate name (Roubertoux & Kerdelhue, 2006) especially nowadays, when individuals bearing this trisomy are diagnosed at birth (or during their prenatal development) on the basis of their genetic rather than their phenotypical characteristics. The extra copy of chromosome 21 results in significant modifications to the body's anatomy (short stature, short hands; Chumlea, Malina, Rarick, & Seefeldt, 1979), and the brain's architecture and function (Becker, Mito, Takashima, & Onodera, 1991; Teipel & Hampel, 2006). Motor control and development have been shown to be atypical in individuals with T21, and their manual skills are often described as "clumsy" (for a review, see Weeks, Chua, & Elliott, 2000). Specific body and brain characteristics, as well as hypotonia, probably all contribute to the atypical development of manual skills in T21 (Lauteslager, Vermeer, & Helder, 1998; Virji-Babul et al., 2008). Participants' mental deficiency may also impair goal representation, decision-making, response selection, and action planning. None of these explanations are mutually exclusive, and according to Latash and coworkers, motor coordination and development in T21 are the result of adaptation, and are linked to the children's individual characteristics (Latash, 2000; Virji-Babul & Latash, 2008).

Children with T21 exhibit specific postural-motor features from birth (Mazzone, Mugno, & Mazzone, 2004) and throughout their childhood and adolescence, despite considerable interindividual variability (Jobling & Mon-Williams, 2000). In the motor domain, research using standardized motor scales has shown that fine motor skills and manual dexterity are severely impaired, and exhibit less developmental progress (Spanò et al., 1999; Volman, Visser, & Lensvelt-Mulders, 2007). Object reaching and grasping have been showed to be impaired in infants with T21 (Cadoret & Beuter, 1994; de Campos, Rocha, & Savelsbergh, 2010). Kearney and Gentile (2003) demonstrated impaired reach-to-grasp control

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and coordination in 3-year-old children, and Charlton and coworkers (Charlton, Ihsen, & Lavelle, 2000; Charlton, Ihsen, & Oxley, 1996) in 8- to 10-year-old children. Reaching movements were slow, jerky, highly variable and inaccurate. These studies showed that the timing of grip closure was impaired, with children frequently hitting the object at a relatively high velocity with fingers in extension. Hand shaping also varied from trial to trial and displayed a number of irregularities, reflecting corrections in grasp size in the course of the action. Children with T21 display greater reliance on feedback guidance than TD children, but the processing of feedback required to control prehension is impaired (Charlton et al., 1996, 2000; Kearney & Gentile, 2003).

Grasp selection has also been shown to be atypical in children with T21. Making a distinction between the *precision grip* (digital prehensile pattern) and the *power grip* (palmar grip, Napier, 1956; Newell & McDonald, 1997), studies have reported a greater proportion of *power grips* in children with T21 aged below 4 years and between 8 and 10 years than in TD children when grasping pegs measuring between seven and 20 cm long (Charlton et al., 2000; Edwards & Lafreniere 1995; Kearney & Gentile, 2003; Moss & Hogg, 1981). All children, however, increase their use of precision grips with age (Moss & Hogg, 1981): in a rod displacement task, Thombs and Sugden (1991) noted that, in children with T21 aged between 6 and 16 years, precision grips predominated from 8 years onward in tasks that offered a choice between a *power* or a *precision* configuration. Children with T21 also present what Charlton et al. (2000) have called an *unusual grasping style*. For instance, "contact [with the object] is made on the underside of the fingers rather than the fingertips" (p. 41, line 34, Charlton et al., 2000). In rod grasping tasks, Moss and Hogg (1981) and Thombs and Sugden (1991) found that children with T21 retained immature or unusual grasps (*reverse transverse palmar grip, reverse transverse digital grip*, and *oblique digital grip*). Some of these grasps involve extreme pronation of the forearm, and may reduce the scope for manipulative movements and induce involvement of the wrist, upper limb or trunk (Elliott & Connolly, 1984). It is important to note that Savelsbergh et al. (2001) demonstrated that hand size could account for the difference between TD children and children with T21 in one-/two-handed grasping. The difference between groups disappeared when hand size was controlled, indicating that the difference between grasping patterns can be attributed to differences in body size.

The developmental differences between typically developing (TD) children and children with T21 present both quantitative and qualitative aspects. For instance, Dunst (1990) and Jobling and Mon-Williams (2000) observed that changes in the motor performances of children with T21 follow a similar pattern to those of TD children, but at a slower pace. Shumway-Cook and Woollacott (1985) and Lauteslager (2004), on the other hand, found that muscular contributions to postural control and postural development follow a rather different pattern of development in children with T21. Concerning fine motor skills, comparisons between children with T21 and TD children matched for developmental age (Battelle Developmental Inventory, Bayley Scales of Infant Development or Stanford-Binet Intelligence Scale) lessen differences between the groups, but do not entirely eliminate them (Charlton et al., 2000; Kearney & Gentile, 2003; Moss & Hogg, 1983). Furthermore, children with T21 perform poorly in the areas of fine motor skills compared with mentally retarded children without T21 but of comparable chronological or mental age (Connolly & Michael, 1986). The development of grip in T21 may therefore present both quantitative and qualitative differences compared with typical development. Using the dexterity items of the Movement Assessment Battery for Children (M-ABC, Henderson & Sugden, 1992), Spanò et al. (1999) observed very little age-related development in T21 children, and the gap between motor performance and chronological age became gradually wider. We therefore hypothesized that the grip specificities of children with T21 contribute to the very low scores of these children on standardized motor scales.

The present study examined the grasp characteristics of children with T21 while they performed simple manual tasks taken from a standardized motor scale (M-ABC, Henderson & Sugden, 1992). The first aim was to find out whether their low scores stemmed partially from their grip specificities. These tasks also had the advantage of requiring participants to manipulate very small objects, compared with those used in previous research on grasping in children with T21, and allowed us to complete the description of grip specificities in children with T21. Finally, we added a task involving an object scaled to the children's hand size to verify the influence of differences in hand size on manual grasping. Our aim was also to identify the qualitative or quantitative aspects of dexterity difficulties, while comparing developmental trends in handgrip specificities in children with and without T21 aged between 4 and 18 years. We assumed that the comparison of the groups' developmental curves would help us to determine the quantitative and qualitative differences between the two.

METHODS

Participants

Thirty-five children with full trisomy 21, aged 51–221 months, took part in the study. Children were contacted through the Trisomie 21 France association. The children's cognitive level was roughly estimated using a nonverbal test (K-ABC Triangles subtest, EDEI-R Practical Adaptation subtest, or Raven's Colored Progressive Matrices). Children were screened either by their special home needs service or by the authors of the paper, when the information was not available. The children's mental ages ranged from below 36 months to 92 months (Tab. 1). The children's fine motor developmental level was also estimated using the child score on the manual task of the M-ABC. The children's motor ages ranged from below 46 months to 84 months (Tab. 1). Thirty-five age-matched typically developing (TD) children aged 50–222 months were included in the comparison group. They all followed the normal curriculum and were assessed in their own homes. Children were matched on their chronological age, on a case-by-case basis, with a difference of no more than six months. All parents gave their informed consent prior to the experiment and very few children refused to perform the tasks.

As it was not possible to ask each child with T21 to perform all three tasks, the reported data were collected from three groups of children with T21 and their respective TD matches (Tab. 1). These three groups overlapped considerably, as 59% of the children with T21 performed more than one task. The effectiveness of the age matching was verified by means of a *t*-test and differences were all nonsignificant. As reported in the literature, the children with T21 had consistently smaller hands than the TD children (Chumlea et al., 1979).

Apparatus and Procedure

Children were observed individually by the first author, in a room that was familiar to them. They were seated at a table, on a height-adjusted chair. The children's right and left hands were filmed by two camcorders (Sony DCR-PC1000E and DCR-HC96 MiniDV), positioned 150 cm above the table and 150 cm in front of the child. Technical equipment was placed in such a way as to cause minimum distraction.

The children were told that there would be a series of games to play and that their hands would be filmed. The maximum finger span, that is, the distance between the tips of the thumb and the index finger, was taken as a measure of hand size (van der Kamp, Savelsbergh, & Davis, 1998). Children were asked to write their name or their signature on a sheet of paper and to show the hand they preferred to use to brush their teeth or comb their hair, in order to determine their preferred hand (PH) and nonpreferred hand (NPH). We then asked the children to perform three manual tasks.

(1) *Posting coins*: This task was taken from the M-ABC (Henderson & Sugden, 1992). It consisted in inserting twelve .1 cm-thick and 3 cm-diameter coins in an 8 cm × 7 cm × 5.5 cm box that had a 3.5 cm × .4 cm slot in the top. The box was placed on the table, to the right or left of the child, and the coins were positioned to the left or right of the child. The child used the hand opposite the box side to pick up and insert the coins in the box. The task had to be completed twice, as quickly as possible, and was repeated with the box placed on the other side, to test both the child's PH and NPH.

Table 1. Age, Gender, Hand Size, and Motor and Mental Age as a Function of Group (Mean, Standard Deviation, and Range)

Task	Group	Gender (Number of Girls/Total)	Hand Size (cm)	Chronological Age (Months)	Mental Age (Months)	Motor Age (Months)
Posting Coins	T21	15/28	13.5 ± 2.1	131 ± 49.5 (51–221)	54.4 ± 20.2 (24–92)	56.3 ± 17.5 (36–84)
	TD	12/28	15.6 ± 2.6	132 ± 49.5 (50–222)		
	Group comparison		$t(1, 53) = 3.1$, $p < .001$	$t(1, 54) = .07$, $p = .9$		
Placing Pegs	T21	16/26	13.7 ± 2	136.1 ± 44.6 (76–221)	55.3 ± 18 (24–92)	56.9 ± 17.4 (36–84)
	TD	9/26	15.9 ± 2.4	134.8 ± 46.7 (70–222)		
	Group comparison		$t(1, 49) = 3.6$, $p < .001$	$t(1, 50) = -.1$, $p = .9$		
Picking up blocks	T21	9/17	13.4 ± 2	123.9 ± 46.1 (61–221)	55.7 ± 19.3 (24–92)	55.8 ± 18.2 (36–84)
	TD	7/17	15.2 ± 2.5	124 ± 15.2 (58–221)		
	Group comparison		$t(1, 30) = 2.6$, $p = .01$	$t(1,30) = 0$, $p = 1$		

Hand size was assessed by measuring the distance between the tips of the thumb and the index finger. Mental age was assessed using nonverbal tests (K-ABC Triangles subtest, EDEI-R Practical Adaptation subtest or Raven's Colored Progressive Matrices). Mean mental ages were based on an assessment of 20 of the 28 participants with T21 who performed the "*posting coins*" task, 19 of the 26 participants with T21 who performed the "*placing pegs*" task and 16 of the 17 participants with T21 who performed the "*picking up blocks*" task. Motor age was assessed using the score on the M-ABC, either for the "*posting coins*" task or for the "*placing pegs*" task. Typically developing participants did not undergo the assessments of mental and motor age.

(2) *Placing Pegs*: This task also belongs to the M-ABC. The child had to place twelve 1 cm-high pegs (with a .5 cm-diameter head) in holes in a board (18 cm × 18 cm). The board was placed on one side of the child and the pegs on the other side. The child used the hand opposite the board side to pick up and place the pegs. The task had to be completed twice, as quickly as possible, and was repeated with the board and pegs switched round, to test both the child's PH and NPH.

(3) *Picking Up Blocks*: Each child was asked to pick up five blocks of the same size from the table, one by one, and put them in a large box. The box was placed on one side of the child and the blocks on the other side. The child used the hand opposite to the box side to pick up the blocks. The size of the blocks was determined by the size of the child's hand. To exclude two-hand grasps, a ratio of .4 was used between maximum finger span (distance between the tips of the thumb and the index) and block side length (van der Kamp et al., 1998). The task had to be completed as quickly as possible and was administered twice, once with the PH and once with the NPH.

The children were given instructions and shown how to perform each task at the beginning of the first trial and also during the task, if necessary. Four to seven practice trials were administered for the M-ABC tasks and one or two for the blocks task. The children were told that the task had to be completed as quickly as possible and verbal encouragements were continuously given. The experimenter tried to reduce the cognitive load of each task as much as possible, so that inability to perform the task was not simply the result of failing to understand the instructions. Children using the wrong hand to complete the task were stopped and the instruction and demonstrations were given once again before the child resumed the task.

Videos were captured offline on a computer and analyzed frame by frame, using editing software (VirtualDub, 1.6.15). Fingers were labeled d1 (thumb), d2 (index), d3 (middle finger), d4 (ring finger), and d5 (little finger). The names of the fingers that came into contact with the object and the contribution of the palm to the grip (i.e., power grip) were recorded (Napier, 1956), as were the name of fingers that were extended during lifting (Wong & Whishaw, 2004). Two independent observers contributed to this work and interrater reliability was high for all tasks (percentage of agreement: 85–86%; kappa = .63–.73). The quantitative dependent variables used in this study were, for each child, the mean number of fingers involved in the grip, the percentage of trials with finger extension and grip variability. Grip variability was calculated for each child, as the ratio between the number of grasp configurations and the number of trials. The number of children presenting atypical finger configurations (grasp or extension) was counted in each group (Tab. 2).

We used the SPSS package for the statistical analyses. The two groups of participants and both hands were compared with a General Linear Model for repeated measures for quantitative variables (number of fingers, percentage of finger extensions and grip variability). Effect sizes were calculated with the partial eta-squared, abbreviated as η_p^2, η_p^2 being the proportion of variability in the dependent measure that is attributable to a factor, other nonerror sources of variance being partialed out (Cohen, 1973). Regressions were performed to assess the effect of age on all quantitative variables. The proportions of children presenting atypical grip and extensions were compared using the chi-square test (likelihood ratio or Fisher's exact test when expected cell counts were <5). The effect size was given with the odds ratio, which indicated the probability of a child belonging to the T21 group displaying the relevant behavior (Field, 2005). Statistical significance was set at $p < .05$.

RESULTS

Posting Coins

When compared with the test's norm, the children with T21 who performed this task had significantly lower scores. More than 42% of the children with T21 presented a level of performance below 4 years, 57% of the children aged 5 years or more presented a level of performance below 5 years, and 67% of the children aged 6 years or more presented a level of performance below 6 years. No child achieved the performance expected for his/her age.

Children with T21 used significantly fewer fingers to grip the coins than their TD peers and the effect size was large (means and standard errors: TD children: $3.7 \pm .08$ and children with T21: $3.2 \pm .07$, $F(1, 54) = 5.47$, $p = .0001$, $\eta_p^2 = .31$). The difference between hands was not significant. The mean number of fingers used in the grip did not significantly depend on age for either hand in either group (TD children, PH: $\beta = -.22$, *ns*, and NPH: $\beta = -.33$, *ns*; children with T21, PH: $\beta = -.15$, *ns*; and NPH: $\beta = -.09$, *ns*). The most frequent configuration of fingers observed in this task was d1/d2/d3. However, some of the grasps displayed by children with T21 were scarcely used, if at all, by the TD children (Tab. 2). A comparison of the number of children who used these grips in each group revealed significant differences. d1/d2 grips were more frequent for the NPH than they were for the PH in the group of children with T21 (Fisher's exact test, $p < .01$). These atypical grip features were present in both the younger and the older children. The palm very rarely contributed to the grip in this task.

Finger extensions were more frequent in the T21 group than in the TD group (TD children: $.6 \pm .4$ and children with T21: 22.9 ± 5.3, $F(1, 54) = 32.3$, $p < .000$, $\eta_p^2 = .37$) and more numerous with the NPH than with the PH, $F(1, 54) = 5.7$, $p = .02$, $\eta_p^2 = .10$. The interaction between group and hand showed that the difference between the two hands was greater in children with T21 than in TD children, $F(1, 54) = 5.37$, $p < .05$, $\eta_p^2 = .09$. In children with T21, finger extensions were present at all ages and their frequency did not significantly decrease with age (PH: $\beta = -.30$, *ns*; NPH: $\beta = -.26$, *ns*). As finger

Table 2. Number and Percentage of Children (in Parenthesis) Presenting Atypical Types of Grasp and Group Comparison for Each Task

			Frequency (%)		Group Comparison	Effect Size
Task (Number of Children)	Type of Grip	Hand	T21	TD	Likelihood Ratio or Fisher's Exact Test of Significance (Two-Tailed)	Odds Ratio
Posting Coins (28)	d1. d2	PH	11 (39.3)	5 (17.9)	3.21	2.98
		NPH	17 (60.7)	7 (25.0)	7.47**	4.64
	d1. d3	PH	3 (10.7)	0	*F*	—
		NPH	7 (25.5)	0	*F***	—
	d1. d3. d4	PH	11 (39.3)	3 (10.7)	6.39*	5.39
		NPH	14 (50.0)	4 (14.3)	8.55**	6
	Power grip	PH	2 (7.1)	0	*F*	—
		NPH	4 (14.3)	0	*F*	—
	d3.d4.d5 extension	PH	10 (35.7)	0	*F****	—
		NPH	15 (53.6)	1 (3.6)	19.7***	31.15
Placing Pegs (26)[1]	d1. d2	PH	19 (76.0)	6 (23.1)	15.04***	10.56
		NPH	23 (88.5)	3 (11.5)	34.89***	58.78
	d1. d3	PH	8 (32.0)	1 (3.8)	*F**	11.76
		NPH	14 (53.8)	0	24.69***	—
	d1. d3. d4	PH	8 (32.0)	3 (11.5)	3.24	2.71
		NPH	6 (23.1)	9 (34.6)	.85	.57
	Power grip	PH	0	0	*F*	—
		NPH	0	1 (3.8)	*F*	—
	d3.d4.d5 extension	PH	6 (24.0)	1 (3.8)	*F***	7.5
		NPH	11 (42.3)	0	18.24***	—
Picking up Blocks (17)[2]	Grip without d2	PH	12 (75.0)	3 (17.6)	11.64**	14
		NPH	8 (50.0)	4 (23.5)	2.53	3.25
	d1, d3, d4, d5	PH	10 (62.5)	3 (17.6)	7.24**	7.78
		NPH	6 (37.5)	3 (17.6)	*F*	2.8
	Power grip	PH	11 (68.7)	12 (70.6)	1	.92
		NPH	13 (81.2)	10 (58.8)	.26	3.03
	d2 extension	PH	9 (56.3)	5 (29.4)	1.47	3.09
		NPH	12 (75)	3 (17.6)	11.64***	14

PH, preferred hand; NPH, nonpreferred hand. All statistics have one degree of freedom. *F*, Fisher's exact test when expected cell counts are <5.
Missing values in the group of children with T21: [1]one missing value with the PH, [2]one missing value for the PH and one missing value for the NPH.
*$p \leq .05$.
**$p \leq .01$.
***$p \leq .001$.

extensions were very rare in TD children, this effect was not tested in this group.

Finger extensions involved every finger (d2, d3, d4, and d5), but were increasingly frequent toward the ulnar side of the hand. The most frequent extension concerned d5 (64% and 84.6% of children with T21 for the PH and NPH respectively) and the least frequent one d2 (24% and 53.8%). The extension of d3 was always associated with the extension of d4 and d5, and the extension of d4 was always associated with the extension of d5. The extension of d3/d4/d5 was observed in 40% (PH) and 57.7% (NPH) of children with T21, but only once in TD children. The d3/d4/d5 extension was present in both the younger and the older children with T21.

Grip variability was based on the ratio between the number of grasp configurations and the number of trials. The difference between TD children and children with T21 failed to reach significance (TD children: $.13 \pm .01$ and children with T21: $.16 \pm .01$, $F(1, 54) = 3.72$, $p = .06$, $\eta_p^2 = .06$), but grip variability was greater with the NPH than with the PH, $F(1, 54) = 5.53$, $p = .02$, $\eta_p^2 = .09$, and declined with age (PH: $\beta = -.54$, $p < .003$; NPH:

$\beta = -.50$, $p < .006$) in children with T21. As finger extensions were very rare in TD children, this effect was not tested in this group.

Figure 1 provides an illustration of grip features in TD children and children with T21 as a function of their chronological age. The low number of fingers involved in the grip in children with T21 did not disappear with age, and was observed in the young adults. Grip variability, however, tended to reduce during development in children with T21, and the difference between children with T21 and TD children decreased.

Placing Pegs

A norm referenced assessment of the children who performed this task revealed a significantly lower score

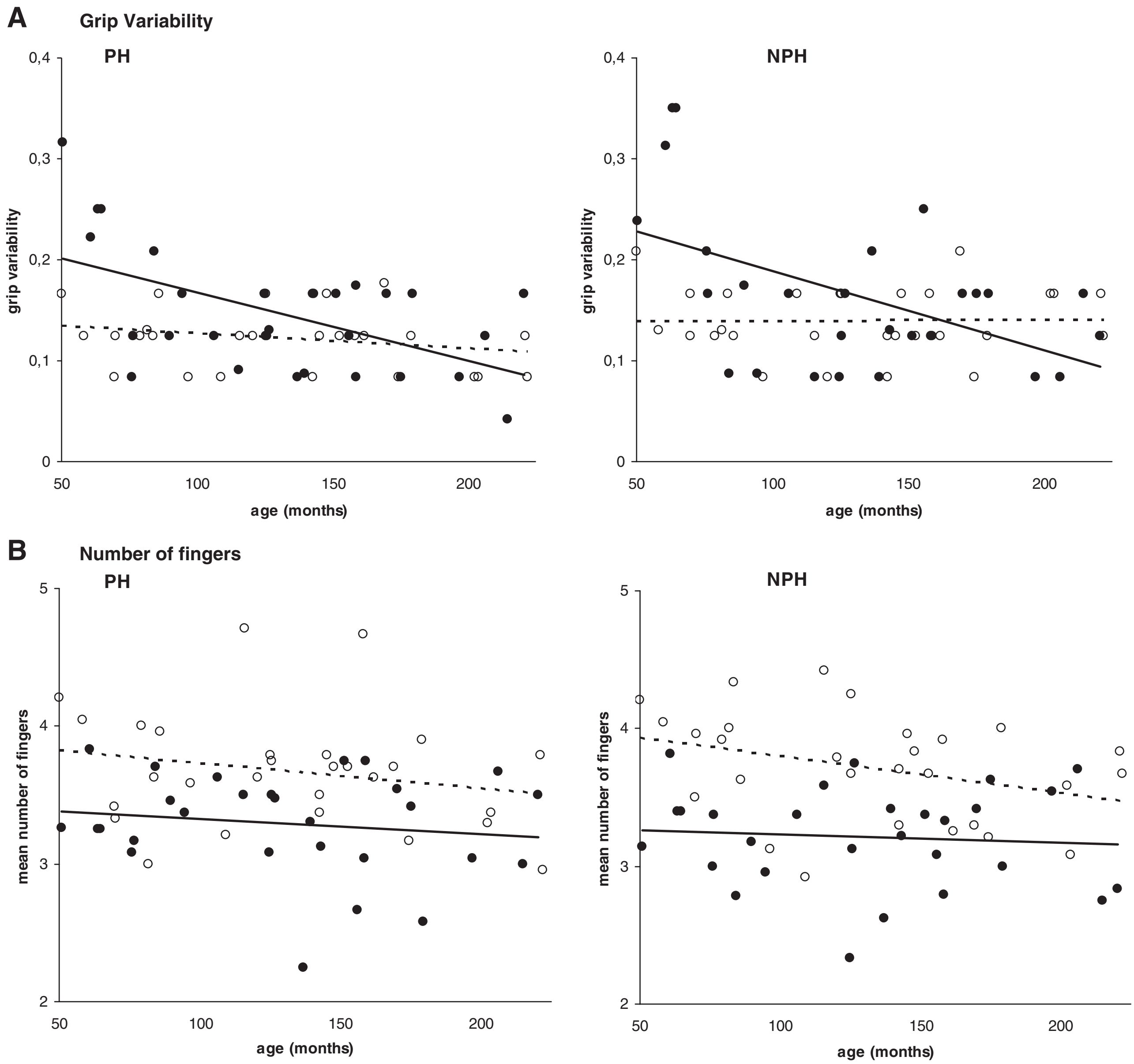

FIGURE 1 Example of grip features in the *posting coins* task for the PH and NPH in TD children (white dots) and children with T21 (black dots) as a function of chronological age. Regression lines are presented for each hand, with a dashed line for TD children and a solid line for children with T21. (A) Grip variability. The developmental effect was significant for both hands in children with T21. The difference between TD and T21 children was not significant. (B) Mean number of fingers involved in the grip. The developmental effect was not significant for either hand. The difference between TD and T21 children was significant.

for the children with T21. More than 96% of the children with T21 aged 7 years or more presented a level of performance below 7 years, and no child aged 8 years or more presented a level of performance corresponding to the age of 8. No child achieved the performance expected for his/her age.

Children with T21 used significantly fewer fingers than TD children to grip the pegs (TD children: $3.3 \pm .08$ and children with T21: $2.8 \pm .05$, $F(1, 49) = 36.59$, $p < .000$, $\eta_p^2 = .43$). The difference between the hands was not significant, nor was the interaction between group and hand. The number of fingers used to grip the pegs did not vary significantly with age (TD children, PH: $\beta = -.09$, *ns*; NPH: $\beta = -.07$, *ns*, and children with T21, PH: $\beta = .06$, *ns*; NPH: $\beta = .04$, *ns*).

In both groups, most of the children used a grip involving d1, d2 and d3. Children with T21, however, displayed grips that were rare or even absent in TD children: d1/d2, d1/d3, and d1/d3/d4 (see Tab. 2). These atypical grips were equally frequent with the PH as they were with the NPH, and remained present across the whole age range. The contribution of the palm to the grip was seen in only one trial, in a TD child.

Children with T21 displayed more finger extensions than TD children (TD children: 18.4 ± 3.9 and children with T21: $1.5 \pm .65$, $F(1, 49) = 28.5$, $p < .000$, $\eta_p^2 = .36$). These extensions were more numerous with the NPH than with the PH, $F(1, 49) = 25$, $p < .000$, $\eta_p^2 = .34$, and the interaction was significant, indicating that this effect was stronger in children with T21, $F(1, 49)=20$, $p < .000$, $\eta_p^2 = .29$. The number of finger extensions did not significantly decrease with age in children with T21 (PH: $\beta = -.13$, *ns*; NPH: $\beta = -.15$, *ns*). As finger extensions were very rare in TD children, this effect was not tested in this group.

Extensions involved all the fingers (d2, d3/d4/d5, d4/d5, and d5), but were more frequent for d5 (48–69% of children with T21) and d2 (44–58% of children with T21). Extensions of d3/d4/d5 were observed in 24–42% of children with T21, but only once in TD children (Tab. 2). The d3/d4/d5 extension was observed at all ages.

Grip variability was greater in children with T21 than in TD children (TD children: $.1 \pm .01$ and children with T21: $.16 \pm .02$, $F(1, 49) = 10.30$, $p < .002$, $\eta_p^2 = .17$) and was also significantly greater for the NPH than for the PH, $F(1, 49) = 6.89$, $p < .01$, $\eta_p^2 = .12$. The interaction between group and hand was not significant. The developmental effect was significant, as variability decreased with age in children with T21 (PH: $\beta = -.53$, $p < .006$: NPH: $\beta = -.39$, $p = .05$). This effect was significant in TD children for the PH (PH: $\beta = -.44$, $p = .02$; NPH: $\beta = -.24$, *ns*).

Picking Up Blocks

Children with T21 used significantly fewer fingers than TD children (TD children: $4.7 \pm .05$ and children with T21: $4.5 \pm .06$, $F(1, 30) = 4{,}36$, $p < .05$, $\eta_p^2 = .13$). The mean number of fingers did not differ between hands and the interaction between group and hand was not significant. The number of fingers used to pick up the blocks did not significantly depend on age, either in TD children (PH: $\beta = -.25$, *ns*; NPH: $\beta = -.34$, *ns*) or in children with T21 (PH: $\beta = -.25$, *ns*; NPH: $\beta = -.07$, *ns*).

As in the other tasks, specific grips were seen in children with T21: grips without d2 and the d1/d3/d4/d5 grip (Tab. 2). These atypical grip features were present across the whole age range. The contribution of the palm to the grip was seen in most of the children in both groups. The difference between the NPH and PH was not significant.

Finger extensions only concerned d2 and d5, and were more frequent in children with T21 than in TD children (TD children: 8.8 ± 2.6 and children with T21: 31.25 ± 4.75, $F(1, 30) = 16.9$, $p < .000$, $\eta_p^2 = .36$). The difference between hands and the group × hand interaction were not significant. The frequency of finger extensions did not significantly depend on age in TD children (PH: $\beta = .01$, *ns*; NPH: $\beta = .06$, *ns*). In children with T21, however, age did influence finger extension frequency for the PH (PH: $\beta = .58$, $p < .05$; NPH: $\beta = .31$, *ns*), with the frequency of finger extensions tending to increase with age.

Grip variability was greater in children with T21 than in TD children and the effect size was large (TD children: $.35 \pm .02$ and children with T21: $.48 \pm .03$, $F(1, 30) = 14.75$, $p < .001$, $\eta_p^2 = .33$). It did not differ between the NPH and the PH, and the interaction between group and hand was not significant. Grip variability did not depend on age either in the TD children (PH: $\beta = .14$, *ns*; NPH: $\beta = -.32$, *ns*) or in the children with T21 (PH: $\beta = .03$, *ns*; NPH: $\beta = .10$, *ns*).

DISCUSSION

The aim of the present study was to examine specific grasp characteristics displayed by children with T21 performing two M-ABC tasks (posting coins and placing pegs, Henderson & Sugden, 1992) and a task that consisted in grasping blocks whose size was adjusted to the children's hand size (van der Kamp et al., 1998). We quantified the number of fingers involved in the grips, finger extensions and grip variability, and classified the grips according to the fingers that were involved and the contribution of the palm to the grip (power grip). Finally, to identify the qualitative and quantitative aspects of the handgrip difficulties, we compared the developmental curves of the children with T21 and their chronological age-matched peers. We therefore performed regression analyses of chronological age on all quantitative variables. After interpreting and discussing the scores on the M-ABC tasks and the grasp features of the children with T21 compared with TD children, we discuss the developmental results.

Movement ABC Scores

The Movement ABC scores indicated that the children with T21 performed poorly on both the manual tasks in this test. Although there was some variability, none of the children with T21 achieved the score expected for their chronological age on either the *coin inserting* or the *peg placing* task. This is in agreement with most of the studies that have investigated impairment of fine motor skills in children with T21 (Connolly & Michael, 1986; Spanò et al., 1999; Volman et al., 2007). However, the tasks we used contained a time constraint and the scoring was based on the time needed to complete the task. Children with T21 have been shown to be slower than TD children (Frith & Frith, 1974), although some studies have failed to demonstrate any difference in tasks that children are asked to perform as fast as possible (see Moss & Hogg, 1987). Besides their slowness, children with T21 also presented specific grasp features that may have contributed to their low scores.

Grasp Features in Children With T21

Some aspects of grasp described in this study were comparable for both the children with T21 and the TD children. The children mostly used a precision grip for small objects (pegs and coins) and a power grasp, that is, a grasp with the contribution of the palm, when picking up the blocks. For this type of grasp, the difference between the groups was not significant: children with T21 never displayed more power grasps than TD children. This result is puzzling, given Charlton et al. (2000)'s study which reported a more frequent use of *whole-hand grasps* by children with T21 than by chronological age-matched TD children when grasping small (.7 cm × 9 cm) and large (2 cm × 20 cm) cylindrical objects. There are two possible explanations for this discrepancy. First, the shape and size of the objects used in the M-ABC tasks (a disk and a peg smaller than 3 cm) meant that they were too small to induce any holding of the object between the ventral surface of the fingers and the palm, such as a 9 cm-long cylinder might induce (Thombs & Sugden, 1991). One could say that they "afforded" more precision grips than power grips in children with T21, as they did in TD children (Napier, 1956; Newell & McDonald, 1997). A second explanation for the absence of any difference between the children with T21 and the TD children in grasping the blocks can be found in Savelsbergh, van der Kamp, and Davis (2001) work. In their study, the shift from one- to two-handed grasping of a cube according to its size was the same in children with and without T21 when the cube sizes were scaled to hand size. In the present study, we scaled block size to hand size and did not observe any difference in the number of power grips between the children with and without T21. This result can be regarded as an extension of these authors' work, suggesting that the contribution of the palm when grasping a block is also determined by body scaling (Savelsbergh et al., 2001; van der Kamp et al., 1998).

Grasp features also differed in many aspects between children with T21 and TD children. First, in each task, the children with T21 included significantly fewer fingers in their grasp than children in the comparison group did. The effect sizes were moderate to large, indicating a clear difference between the groups. In a bead grasping situation, Wong and Whishaw (2004) divided grasps into seven categories, ranging from the *proper pincer*, where the thumb and index digits were used, to the *five-digit grasp*, where the tips of all five fingers were used. As the size of the bead increased (from 3 to 16 mm), they observed a gradual shift from the two-digit grasp toward three- or four-digit grasps. According to the authors, the pincer grasp was most appropriate for the smallest object because of the limited contact space, and participants used more three- and four-digit grasps with beads of the largest diameters as the latter provided more contact space. They concluded that *the more digits recruited, the more stable the grip* (page 121, Wong & Whishaw, 2004). We used objects that were bigger and had more complex shapes than Wong and Whishaw (2004) did. Furthermore, the participants had to orientate and manipulate the object in the hand extremely accurately in order to perform the tasks, namely, inserting the coin in the slot in the top of the box, and inserting the peg in a hole in the pegboard. Elliott and Connolly (1984)'s description of manipulative hand movement suggests that the three-finger grasp (dynamic tripod) allows more coordinated movements of the digits for manipulating an object within the hand than a pincer grasp between the pulp surfaces of the opposed thumb and index finger (pinch). In this study, we therefore assume that using three or more fingers made it easier to orientate the object and thus perform the task. Accordingly, by using fewer fingers to grasp the coins or the pegs, the children with T21 showed themselves to be less efficient in their grip choice than their TD peers. This may have contributed to their low score on the M-ABC, by slowing down coin insertion or peg placement performance.

The children with T21 displayed atypical grasps throughout the study, some of which were rarely or never observed in TD children. For instance, children with T21 used d1/d3 grips or d1/d3/d4 grips and used many grips that did not involve d2. The d1/d3 grip has also been reported in children with T21 below 4 years by Edwards and Lafreniere (1995). In their bead grasping study, Wong and Whishaw (2004) observed few occurrences of these *improper pincer* or *improper triangular grasps* (d1/d3; d1/d4; d1/d3/d4) in TD children between 5 and 12 years. This suggests that these atypical grasps could be an immature form of grasping that remains present in children with T21 (Moss & Hogg, 1981; Thombs & Sugden, 1991). It is interesting to note that in a previous study, we investigated specific grasp characteristics in children with Williams–Beuren syndrome (Stefanini, Bello, Volterra, & Carlier, 2008). Children with this syndrome aged between 9 and 11 years appeared to use a lateral grip, where the pad of the thumb was placed on the outside of the index finger. Even when we searched for this grasp, we failed to observe it in our sample of children with T21, thus reinforcing our hypothesis of specific motor behaviors for specific developmental disorders (Carlier et al., 2006; Gerard-Desplanches et al., 2006).

Together with the fewer fingers observed in children with T21, the atypical grip that many of these children displayed may have resulted from difficulty in selecting the right grip to perform the task. Object reaching, grasping, and manipulation require an accurate representation of the object (size, shape, etc.), and the task must be planned as a function of the individual's arm and hand (see Jeannerod, 1988). Motor planning has already been shown to be difficult for children and adults with T21 (Mon-Williams et al., 2001; Moss & Hogg, 1987) and this difficulty probably contributed to the slowness of M-ABC task completion.

A third specific feature of grasp in children with T21 in this study was the high number of finger extensions observed. Finger extensions appeared more often in the T21 group than in the TD group and the effect sizes were large. The extensions concerned either d2 or d4 and d5. Many children with T21 extended the whole of the ulnar side of the hand (d3/d4/d5 fingers), which is something that the TD children never did. Halverson (1931) is the only author to have specifically described finger extension in children while studying the development of prehension. During the first successful prehension using the superior pincer grasp, Halverson observed that the ulnar fingers were extended like "stairs" to provide stability of the grip. More recently, in their study of early block prehension, Geerts, Einspieler, Dibiasi, Garzarolli, and Bos (2003) described several grips featuring finger extensions. Their frequency was very low and decreased between 14 and 25 months. In nondisabled adults, Wong and Whishaw (2004) reported very few finger extensions when studying the posture of the nongrasping finger in a bead grasping situation. In their study, the fingers that did not contribute to the grip were mostly adducted and flexed. In children with T21, Edwards and Lafreniere (1995) reported frequent d2 or d5 extensions below 4 years. If ours is the first study to report d3/d4/d5 extensions in children with T21, it is probably because it involved small objects. Does this extension reflect the display of excessive grasping force by children with T21? Adults with T21 have been shown to exert greater static grip force on an object they are lifting than a control group (Cole, Abbs, & Turner, 1988) and are less able to control individual fingers (Latash, Kang, & Patterson, 2002). The finger extension while grasping could result from a *fork strategy*, which consists in producing an equivalent amount of force in each finger. These extensions could also represent, as Halverson suggested, a way of ensuring grip stability (Halverson, 1931). However, we believe that finger extension contributes to the observed clumsiness of children with T21.

The difference in grip variability between children with and without T21 was either significant or displayed a trend toward significance. Children with T21 used more variable grasps than TD children did. High within-participant variability has already been reported in children with T21 (for example, Charlton et al., 1996; Jobling & Mon-Williams, 2000; Latash, 2000). Trial-to-trial variations in grasp may stem from a deficit of stability in the acquisition of sensorimotor skills in children with T21, as Dunst (1990) has suggested. This inefficient learning and developmental instability probably undermines motor development in children with T21 (Latash, 2007).

The comparisons between preferred and nonpreferred hands were never significant in the picking up blocks task. They did, however, highlight a few significant differences in the two M-ABC tasks: finger extension and grip variability were more numerous with the NPH than with the PH. Concerning finger extensions, interaction effects tended to reveal a greater difference between the PH and NPH in children with T21. The overall tendency was therefore to observe poorer performances with the NPH than with the PH (finger extensions, atypical grasps, and variability), probably reflecting the fact that the PH is more accurate than the NPH in precision tasks. Other researchers have failed to demonstrate any clear difference between the PH and NPH on the qualitative aspects of manual grasping in TD children and young and older adults (Wong & Whishaw, 2004). In T21, studies have reported ambiguous laterality: hand inconsistencies and crossed hand-foot preferences (Carlier et al., 2006; Gerard-Desplanches et al., 2006). In the present study, however, children with T21 presented more strongly dissociated performances between each hand.

Taken together, the specific aspects of grip in children with T21 surely contribute to the clumsiness of individuals with T21 (Latash, 2007) and to the children's low scores on the M-ABC tasks: fewer fingers involved in the grip, more finger extensions, greater variability, and so on. The grip features of children with T21 probably helped to reduce the scope for manipulative movements and induced involvement of the wrist, upper limb or trunk (Elliott & Connolly, 1984), which is often observed in children with T21 performing manual tasks. We therefore suggest that future studies check the trunk posture of children during manual tasks to clarify the link between atypical grip pattern and the involvement of the body in grasping in children with T21.

This study of grasp features has several limitations. Because each child did not perform the whole set of tasks, we were not in a position to compare grasps between tasks. It would have been interesting to see whether object size and task goal constrained grasp in TD children and children with T21 (Charlton et al., 2000). Second, the high speed requirement was maintained in this study in order to satisfy the M-ABC test condition. This means that movement may have been influenced by the participant's level of motivation or attention, which may in turn have increased task completion times in children with T21 (Moss & Hogg, 1987). We think that this constraint probably strengthened the difference between children with and without T21.

Developmental Trends in Children With T21

The developmental sequence of motor milestones is a very fruitful area of research when it comes to understanding the development of abilities in atypical children. We assumed that comparing developmental trends in children with and without T21 would help us to distinguish developmental delay from atypical development. Our results showed that some of the specificities of the children with T21 changed with age, while others did not. Since the study was cross-sectional, our results must, however, be treated with caution.

The only significant effect of age in TD children was a decrease of variability in *placing pegs* with the PH. In children with T21, significant age effects were more frequent. Grip variability tended to diminish with age in all tasks, except for *picking up blocks*. The latter may have reflected a ceiling effect, as the task was very simple and included few constraints. The decrease in variability with age has been shown to be characteristic of postural-motor development (see, e.g., Schmitz, Martin, & Assaiante, 2002). In children with T21, Thombs and Sugden (1991) observed an age-related increase in grip consistency during peg displacement, resulting in the chosen grip being maintained throughout the peg moving task. Our results confirm that children with T21 gradually acquire the use of an effective motor schema for grasping, but at a slower pace than TD children. As a result, the developmental effect was not significant in TD children, but significant in children with T21. This developmental change argues in favor of a developmental delay in grasp variability in children with T21.

Other specific grasp features exhibited by the children with T21 did not change with age, and the difference between TD children and children with T21 remained stable between 4 and 18 years. For instance, the mean number of fingers involved in the grasp did not show any significant developmental effect. In this case, the fact that children with T21 used fewer fingers to grasp the coins or the pegs seems to reflect a specific characteristic. Furthermore, many atypical grasps, such as the d1/d3 and d1/d3/d4/d5 grips, and the d3/d4/d5 extension, seemed to be retained throughout. Children presented these specificities between the ages of 4 and 18 years. These manual characteristics may also stem from the T21 state and may not, therefore, constitute a quantitative difference between the groups. Spanò et al. (1999) also observed that children with T21 showed little development between 4 and 14 years for some aspects of fine motor skills, whereas other aspects of motor development did display age-related development, with delayed but regular acquisitions. The authors concluded that the delayed perceptual-motor development exhibited by children with T21 is not evenly distributed across all tasks (Spanò et al., 1999).

Because there is a dearth of information concerning skilled behavior in children with T21 beyond 4 years of age, this study explored specific manual characteristics exhibited by children with T21 between 4 and 18 years. We chose not to compare our sample of children with T21 with children of the same developmental/mental age. The effect of mental age on motor skills has often been demonstrated, and underscores the importance of referring to a developmental age-matched group, assuming that this type of comparison is indeed meaningful (Carlier & Ayoun, 2007). Research using this paradigm has, however, yielded inconclusive results (Charlton et al., 1996; Jobling & Mon-Williams, 2000). Furthermore, Spanò et al. (1999) recommended looking for explanations other than IQ for the various perceptual-motor difficulties experienced by children with T21.

In conclusion, children with T21 achieve very low scores on norm-referenced dexterity evaluations between the ages of 4 and 18 years. There may be a number of distinct, but not mutually exclusive, explanations for the difficulties that children with T21 have in producing rapid, efficient, smoothly coordinated and context-appropriate actions. The present examination of manual skills not only sought to describe movement specificities in T21, but also attempted to analyze developmental trends. While a cross-sectional study cannot yield a true description of development, the data suggest that T21 is responsible for both the immaturity and the specificity of manual skills. The development of manual skills relies on a complex interplay between the specific anatomy of the child's body and his or her muscular hypotonia and cognitive impairment. This interplay changes with age, experience and learning, and results in specific grasp adaptations in this group of children. Our study contributes to current understanding of perceptual-motor development in children with T21, placing the emphasis on atypical development rather than on developmental delay, and underlines the importance of studying perceptual-motor development within the context of the entire system involved in producing the behavior (Thelen, 1995). Future research should concentrate on one of these aspects and on a large group with a narrower age range, including more cognitive and motor tasks, in order to disentangle the relative contributions of the different factors (small hand, hypotonia, and cognitive impairment) to the impairment of manual skills.

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