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Association of children's toothbrushing and fine motor skills: a cross-sectional study

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Abstract: Fine motor skills (FMS) allow for the control and coordination of the distal musculature of hands and fingers, a skill required to brush teeth. The objective of this study was to investigate the association between FMS and toothbrushing efficacy. This cross-sectional study included 42 low-income Latino children aged 5 to 9 years from Pasto, Colombia. Toothbrushing efficacy was determined by the children's dental plaque Quigley-Hein Index (QH-I) mean-score difference from before and after toothbrushing. FMS were evaluated using the 5–15R parent evaluation, the spiral drawing Archimedes test, and a neurodevelopmental assessment of movements and prehension patterns during toothbrushing. A descriptive analysis was performed to assess the characteristics of FMS and children's toothbrushing, and a generalized linear model was used to determine associations between these skills and toothbrushing efficacy. Eighty-six percent of the children had at least one difficulty with FMS, and in 7%, they interfered with daily activities. Fourteen percent presented a moderate pattern in the Archimedes test, and 43% had inefficient prehension patterns. Toothbrushing reduced the QH-I by a mean of 1.45 (SD = 0.78–2.12) ($p < 0.001$). Toothbrushing efficacy was only significantly associated with age (mean-difference = -0.315, 95%CI: -0.481 to -0.148, $p < 0.001$). FMS and toothbrushing efficacy were not significantly associated. Other components of fine motor control should be analyzed to understand the kinetics of toothbrushing.

Keywords: Child; Motor Skills; Toothbrushing; Neurodevelopmental Disorders; Hand Strength.

Introduction

Children develop gradually in different stages; they show qualitative changes in behavior and acquire new types of abilities, among them fine motor skills (FMS). The latter "encompass control and coordination of the distal musculature of the hands and fingers"[1] and are associated with brain, spinal cord, peripheral nerve, muscle, or joint functions.[2] In fine motor integration, these skills synchronize small movements with the eyes, and fine motor precision is based on a minimal visual-perceptual component. Furthermore, children's neurodevelopment includes the refinement of neurological and fine motor skills, language, and social adaptation skills, and is strongly predictive of later academic performance and intellect[3,4] and cognitive performance later in life.[5]

Toothbrushing efficacy has been associated with a range of factors, such as techniques[6] and frequency,[7] and has recently been associated with high socioeconomic status,[8] may depend on motivations[9] or FMS.[10,11] Children start to become familiar with the toothbrush at approximately five years of age, when they start to develop their FMS, such as grasping a pencil. Although this activity is supervised and predicted by their parents' knowledge[12] in early stages, toothbrushing techniques involve skills that sometimes may be performed incorrectly, not only because of inadequate motor process learning during childhood, but also because of a neurodevelopmental maturation disorder. Consequently, lateral, contralateral, up-down, back-forward, circular movements or toothpaste top screwing, for example, could be important indicators of neurodevelopment.

Although there have been few reports about this topic in the literature, it has been documented that after a six-month educational toothbrushing program, 7- to 8-year-old participants showed significantly greater plaque reduction than 6-year-old children; the authors concluded that this may have been due in part to better comprehension and more developed FMS.[10] Likewise, toothbrushing techniques were evaluated in 6- to 8-year-old children, and the authors found that the ideal manual dexterity required for toothbrushing is developed above 8 years of age,[6] which may be because in this period, children can improve the skills required for sulcular brushing.[11] According to toothbrushing techniques, plaque removal efficacy was significantly high with the modified Bass technique, followed by the horizontal scrub technique, and the least effective one being the Fones technique in 6- to 8-year-old children,[6] an outcome probably related to FMS development at that age.

Toothbrushing, measured via plaque indices, may be associated with different FMS and could serve as a proxy to screen for the development of these skills in children. If such an association were established, dentists—who see children from early on in their lives—may be able to assist in detecting signs of neurobehavioral disorders and provide early and appropriate referrals. Moreover, children with known FMS limitations should be specifically educated on toothbrushing. In the present study, we aimed to associate FMS with toothbrushing in a cross-sectional sample of low-income Latino children. We hypothesized that there would be a significant association between FMS, measured via movements and prehension patterns, and toothbrushing.

Methodology

Study design, settings, and sample

This observational study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[13] A cross-sectional study on low-income Latino children from Pasto, southern Colombia, was designed. As an undeveloped region, approximately 65% of Pasto's population has a low-income socioeconomic status.[14] Sampling was conducted in two public schools. A water or electrical service receipt was used to classify the students' socioeconomic status. All children in Colombia enroll in primary school, with public schools being tuition free. Primary school is structured into six years of study. The first year is preschool, after which students complete five more years of basic learning.

Since sampling was limited by the schools to only select a small number of students (the principals wished to control the number of videos and pictures and to avoid classes being disrupted frequently by researchers), a convenience sample of 50 children was approached; among them, 42 (84%) boys and girls, aged 5 to 9, were recruited between September 2019 and March 2020. Female and male children with and without learning difficulties that may be related to conditions such as attention deficit disorder (ADD), dyslexia, attention deficit hyperactive disorder (ADHD), dysgraphia, dyscalculia, and dyspraxia were included, as academic institutions in Colombia embrace the registration of disabled individuals according to Colombian law.[15] Children who were unable to provide informed consent from their parents (n = 3), whose parents had not completed a FMS questionnaire (n = 3), or who were absent during different examination opportunities were excluded (n = 2).

Measures and procedures

Toothbrushing efficacy

Toothbrushing efficacy (plaque removal by tooth brushing, measured via plaque score differences before and after brushing) was assessed using photos. These were recorded using a Nikon Coolpix camera with a Nikkor 18x wide optical zoom (18.1 megapixels) (Kabushiki-gaisha Nikon, Shinagawa, Tokyo, Japan). All recordings were taken under standardized light conditions in the same room and under early natural daylight. The camera flash was disabled, the children were asked to open their mouths naturally, and their cheeks were retracted with a cheek retractor (zdent, Henan Baistra, Zhengzhou, China). The distance used was between 9.8 and 10.2 cm. Photos were taken in sextants: Sextant 1 (53–63, which may include 11–12–21–22), Sextant 2 (54–55, which may include 16), Sextant 3 (64–65, which may include 26), Sextant 4 (73–83 may include 31–32–33–41–42–43), Sextant 5 (74–75, which may include 36) and Sextant 6 (84–85, which may include 46). On the upper teeth, only buccal surfaces were assessed and on the lower teeth, only lingual surfaces were evaluated. Before the photos, dental plaque was disclosed using a plaque revelator (Ditonos, Eufar, Bogotá, Colombia).

The Quigley-Hein index[16,17] (QH-I) was utilized to determine plaque removal and obtained by a calibrated dentist. The scores for this index range from 0 to 5 (from no plaque to plaque covering two-thirds or more of the crown of a tooth), with a value assigned to each evaluated buccal or lingual non-restored surface. To determine the intrarater reliability, 10% of teeth were re-evaluated 2 weeks later, with only one surface per tooth being assessed. The intrarater reliability was kappa = 0.85.

The QH-I was assessed before toothbrushing (baseline) and after toothbrushing. We redisclosed the teeth to evaluate the remnant dental plaque after brushing. The mean score difference in the QH-I was used as a proxy for toothbrushing efficacy.

This index in certain areas also was employed as a proxy for certain toothbrushing movements, allowing us to assess FMS in more detail. To evaluate back-forward[18] and/or spiral movements,[19] the buccal surfaces of the upper anterior, upper right, and upper left sextant were assessed. To evaluate back-forward movements, the lower lingual surfaces were examined. To evaluate more complex vertical movements, such as up-down,[18] the lingual surfaces of the lower anterior sextant were investigated. They were coded dichotomously ["yes" and "never/seldom"]. Additionally, dissociative movements[20] were scrutinized to determine if children were doing the same or similar movements to their hands with their forearms and arms at the same time.

Toothbrushing activities were further recorded using videos to capture associated movements and prehension patterns (see below). A standardized kit (Colgate-Palmolive, Cali, Colombia) with toothpaste and toothbrush was provided.

Fine motor skills

For the evaluation of FMS, the "Motor skills – fine motor skills" section (items from 8–17) of the validated 5–15R (or Five-To-Fifteen-Revised)[21,22] parent questionnaire was used. This questionnaire was developed by a group of Nordic experts in developmental disorders and consists of 181 statements covering the domains of motor function, attention/executive function, language, memory, learning, social skills, and internalizing and externalizing behavioral problems. Each item is rated based on the "does not apply," "applies sometimes/to some extent" or "applies definitely" response scale. Scores for the different domains can be compared with norm tables. The 5-15R norm tables include means and 90th and 95th percentile values for different age groups, *i.e.*, 6–8, 9–12, and 13–15-year-olds. Children scoring above the 90th percentile are considered to have problems warranting clinical evaluation.[21] We obtained permission to use this version through the 5-15R organization.

To date, the 5–15R has been translated into English, Spanish, Swedish, Danish, Finnish, Norwegian, Estonian, and Russian. This Spanish version of the 5–15R has had excellent (Cronbach's alpha = 0.98)[23,24] and adequate subdomain (Cronbach's alpha = 0.77) internal consistency coefficients for FMS. To obtain a semantic Spanish equivalence (culture-specific) of the subdomain, we completed four steps: translation, synthesis, back-translation, and pre-testing. After estimating its reliability, we found that the internal consistency of this version was good (Cronbach's alpha = 0.83). The questionnaire was pre-tested on a sample of 10 mothers with children who ranged in age from 5 to 9 years old and attended the Dental Clinic at Universidad Cooperativa de Colombia in Pasto, Colombia. As pre-testing confirmed the understanding of the translated instrument, it was used in further steps for this study.

FMS were further assessed by having the children draw a picture of a spiral according to a template (12 cm x 12 cm) (4.42" x 4.42") printed on a sheet of paper (Archimedes test).[25,26] The children were instructed to place the pen in the middle of the spiral before the tracing started. They were not allowed to lean on the drawing board with their hand or arm. They were asked to trace the spiral as accurately and as quickly as possible using their dominant hand (right or left). The test was recorded as 0 = *a smoothly drawn spiral with minimal deviation* (normal), 1 = *the line deviates from the pattern slightly* (mild), 2 = *the line is completely outside of the pattern* (moderate) and 3 = *the line is completely outside of the pattern and crosses the template* (tremor). To determine the intrarater reliability, 36% of the sample (15 children) was re-evaluated two weeks later (kappa = 0.82).

Further movements/prehension patterns, such as screwing the toothpaste top, immature or inefficient prehension,[27,28] and in-hand movements, such as palm-to-finger translation, simple and complex rotations,[29-31] and movements when grabbing the toothbrush, were evaluated and coded dichotomously [*can/uses* and *never/seldom*]. Additionally, coordination and visual-motor coordination skills were evaluated when the children put the toothbrush into their mouths (toothbrush grip, motor dexterity, and coordination), as well as when they unscrewed the toothpaste top and put the foam cream on the toothbrush, which was assessed in the toothbrushing videos by a calibrated neuro-pediatrician. To determine intrarater reliability, 36% of the sample (15 children) was re-evaluated two weeks later for movements/prehension patterns (kappa = 0.87), movements when grabbing the toothbrush (kappa = 1.00), coordination (kappa = 0.84), and visual-motor coordination (kappa = 1.00).

The assessed movements[27,28] are summarized in Figure. In this figure, we included a dynamic tripod pattern because it might not be proper to perform some movements required to clean the teeth efficiently, although it indicates mature prehension when holding a pencil.

Statistical analysis

After descriptive analysis, bivariate and generalized linear regression models were used to assess the associations between FMS and toothbrushing measured through QH-I mean-score differences. First, Pearson and Spearman's rho coefficients were used to estimate the strength of the correlations between all FMS from the 5–15R questionnaire and the QH-I score. Second, spiral drawing (Archimedes test); immature prehension patterns; inefficient prehension patterns; simple rotation; complex rotation; movements from hands and forearms; movements from hands, forearms and arms; contralateral movements; back-forward movements; and spiral movements were employed as independent variables. All variables were entered into the model equation and then sequentially removed according to their association and p-values

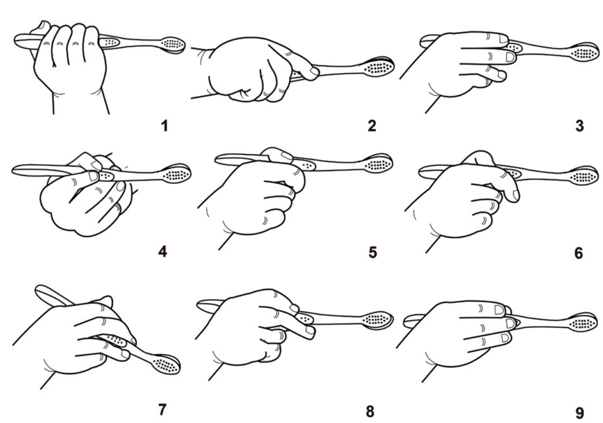

Figure. Immature prehension patterns: 1. palmar supinate, 2. radial/digital, 3. static tripod and 4. dynamic tripod. Inefficient prehension patterns: 5. thump wrap, 6. thumb tuck, 7. interdigital brace, 8. supinate grasp, and 9. index (five finger) grasp.

through a backward elimination method. Missing values due to children having lost teeth were not imputed but occurred infrequently (1% of sextants were missing). The level of significance was set at p < 0.05. Data analyses were performed using SPSS, Version 27 (IBM, Armonk, US).

Results

The sample consisted of 23 boys (55%) and 19 girls (45%). According to age, 3 (7%) children were 5 years old, 9 (21%) were 6 years old, 16 (38%) were 7 years old, 4 (10%) were 8 years old, and 10 (24%) were 9 years old.

Fine motor skills

Table 1 shows the children's FMS perception by parents according to the 5–15R. Eighty-six percent of the children had at least one difficulty with these skills. However, only 5 (12%) exhibited values above the 90th percentile. There was only one domain with statistically significant differences between the sexes, namely, *difficulty using a knife and fork*; girls (7%) had more difficulties than boys (0%) (p = 0.006). When asked "Do problems with motor function interfere with your child's daily function?" 24 parents (57%) answered *not at all*, 15 (36%) *a little*, and 3 (7%) *pretty much*.

Using the Archimedes test, 29 children (69%) displayed a smoothly drawn spiral with no or minimal deviation (no tremor), with significantly more girls (18%) demonstrating a normal pattern than boys (12%) (p = 0.020). Thirteen children (31%) exhibited limitations when drawing; among them, 7 (17%) presented a line leaving the pattern slightly (mild), and 6 (14%) drew a line completely outside of the pattern (moderate). The latter pattern was more frequent in boys (11%) than in girls (0%) (p = 0.020).

Tables 2 and 3 describe different movements and prehension patterns related to FMS assessed during toothbrushing or when grabbing a toothbrush. We found statistically significant differences between age groups for screwing the toothpaste top (p = 0.004) and palm-to-finger translation (p = 0.008), with older children having fewer problems, and between the sexes for grabbing a toothbrush generating movements from the hands, forearms and arms, being more frequent in boys (p = 0.034). In this sample, only 2 (5%) and 7 (17%) children made spiral and up-down movements, respectively. According to coordination and visual-motor coordination, 9 cases (21%) showed minimal dyspraxia, and 7 children (17%) had a lack of attention.

Toothbrushing

The baseline QH-I mean (standard deviation) was 2.78 (1.86–3.70). The boys revealed a mean of 2.87 (1.94–3.80), and the girls showed a mean of 2.68 (1.75–3.61) (p = 0.525). According to age, 5-years-old children exhibited a mean of 2.60 (1.89–3.31); 6-year-old children demonstrated a mean of 2.65 (1.79–3.51); 7-year- old children presented a mean of

Table 1. Fine motor skills perception according to the 5-15R questionnaire. Parents completed this questionnaire for their children (n = 42).

Child's use of his or her hands	Does not apply		Applies sometimes/ to some extent		Applies definitely	
	n	%	n	%	n	%
Does not like to draw, has difficulty drawing figures that represent something	30	71	4	10	8	19
Difficulty handling, assembling, and manipulating small objects	37	88	3	7	2	5
Difficulty pouring water into a glass without spilling it	34	81	6	14	2	5
Often spills food onto clothes or table when eating	20	48	17	40	5	12
Difficulty using a knife and a fork	21	50	14	33	7	17
Difficulty buttoning or tying shoelaces	23	55	15	35	4	10
Difficulty using a pen (*e.g.*, presses too hard, hand is shaking)	35	84	6	14	1	2
Has not developed a clear hand preference, i.e., is neither clearly right-handed nor left-handed	34	81	4	9	4	10
Writing is slow and laborious	20	48	14	33	8	19
Immature pencil-grip, holds the pen in an unusual manner	33	78	7	17	2	5

Table 2. Movement/prehension patterns related to fine motor skills assessed during toothbrushing (n = 42).

Movement/prehension	Items	n	%
Screwing the toothpaste top	Child can screw the toothpaste top (normal)	29	69
	Child never/seldom performs this movement	13	31
Immature prehension pattern: Underlying intrinsic hand strength, finger isolation and hand separation have not yet developed	Not present (normal)	31	73
	Yes, immature prehension pattern	11	27
Type of immature prehension pattern when handling the toothbrush	No immature prehension pattern (normal)	31	73
	Palmar supinate	2	5
	Radial/digital	3	7
	Static tripod	2	5
	Dynamic tripod	4	10
Inefficient prehension pattern: Holding the toothbrush in a way that does not allow the usage of the finger muscles to move quickly with control	Not present (normal)	24	57
	Yes, inefficient prehension pattern	18	43
Type of inefficient prehension pattern when handling the toothbrush	No inefficient prehension pattern (normal)	24	57
	Thump wrap	6	15
	Thumb tuck	-	-
	Interdigital brace	1	2
	Supinate grasp	3	7
	Index (five finger) grasp	8	19
Palm-to-finger translation can be performed	Child can perform this translation (normal)	31	74
	Child never/seldom performs this translation	11	26
Simple rotation: Ability to roll a small object between the thumb and fingertips	Child can perform a simple rotation with the hand (normal)	39	93
	Child never/seldom performs this movement	3	7
Complex rotation: Ability to rotate objects with the fingertips	Child can perform complex rotation with the hand (normal)	16	38
	Child never/seldom performs this movement	26	62

Table 3. Movements related to fine motor skills assessed during grabbing the toothbrush in toothbrushing activity (n = 42).

Movement	Items	n	%
Movements from hands	Child only uses the hand to perform movements for toothbrushing (without the forearms and arms)	40	95
	Child never/seldom performs this movement	2	5
Movements from hands and forearms	Child uses the hand and forearms to perform movements for toothbrushing	39	93
	Child never/seldom performs this movement	3	7
Movements from hands, forearms and arms	Child uses the hand, forearms, and arms to perform movements for toothbrushing	23	55
	Child never/seldom performs this movement	19	45
Lateral movements	Child uses the lateral movements to perform toothbrushing	41	98
	Child never/seldom performs this movement	1	2
Contralateral movements	Child uses the contralateral movements to perform toothbrushing	40	95
	Child never/seldom performs this movement	2	5
Up-down movements	Child uses the up-down movements to perform toothbrushing	7	17
	Child never/seldom performs this movement	35	83
Back-forward movements	Child uses back-forward movements to perform toothbrushing	41	98
	Child never/seldom performs this movement	1	2
Spiral movements	Child uses spiral movements to perform toothbrushing	2	5
	Child never/seldom performs this movement	40	95

3.17 (2.33–4.01); 8-years-old children had a mean of 2.83 (2.01–3.65), and 9-year-old children displayed a mean of 2.31 (1.23–3.39) (p = 0.220). Details on QH-I after brushing and the mean difference in QH-I before and after brushing (i.e., toothbrushing efficacy) are displayed in Table 4. For all areas/movements, a significant reduction in the QH-I was confirmed. The differences before and after toothbrushing (i.e., efficacies) were highest for lateral and contralateral (back-forward, spiral) movements in the upper teeth.

Fine motor skills and toothbrushing efficacy

The overall Pearson's correlation coefficient between the mean-difference QH-I score and the total score of the parents' perceptions of their children's FMS was r = 0.305, p = 0.049. Interestingly, a higher correlation was observed in items such as *often spills food onto clothes or table when eating* (rho = 0.296, p = 0.057), *difficulty using a knife and a fork* (rho = 0.351, p = 0.023), and *difficulty buttoning or tying shoelaces* (rho = 0.288, p = 0.065) (Table 5).

In bivariate linear regression, variables such as age (mean-difference= -0.240, 95%CI: -0.396 to -0.094, p = 0.001), sex (-0.456, 95%CI: -0.833 to -0.080, p = 0.017), and complex rotation (-0.423, 95%CI: -0.814 to -0.033, p = 0.034) were significantly associated with toothbrushing efficacy. In multivariable regression using a generalized linear model, we found significant negative associations with age only (-0.315, 95%CI: -0.481 to -0.148, p < 0.001) (Table 6). This means that while age increases, the dental plaque score decreases; as a result, toothbrushing is more effective over time.

Table 4. Toothbrushing efficacy was measured as the Quigley-Hein index (QH-I) mean-score differences before and after toothbrushing. Plaque on different surfaces was used as a proxy for certain toothbrushing movements, allowing us to better characterize which movements were performed with a certain degree of efficacy.

Dental plaque scores	Regular toothbrushing						p-value[a]
	Baseline		Final		Difference		
	mean	*SD*	mean	*SD*	mean	*SD*	
QH-I Overall	2.78	1.86–3.70	1.33	0.55–2.11	1.45	0.78–2.12	< 0.001
Upper incisors/horizontal (back-forward, spiral)	2.42	1.11–3.73	0.84	-0.14–1.82	1.58	0.6–2.56	< 0.001
Upper right/lateral (back-forward, spiral)	2.80	1.29–4.31	1.12	–0.18–2.42	1.68	0.51–2.85	< 0.001
Upper left/contralateral (back-forward, spiral)	2.78	1.24–4.32	0.98	-0.08–2.04	1.75	0.37–3.13	< 0.001
Lower incisors/vertical (up-down)	3.08	1.92–4.24	1.64	0.42–2.86	1.43	0.49–2.37	< 0.001
Lower right/lateral (back-forward)	2.60	1.87–3.33	1.65	0.72–2.58	0.95	0.3–1.60	< 0.001
Lower left/contralateral (back-forward)	2.70	2.04–3.36	1.92	1.01–2.83	0.76	0.08–1.44	< 0.001

SD: standard deviation; [a]Derived from a paired *t-test*. Statistical significance set at $p < 0.05$.

Table 5. Correlations between parents' perceptions of their children's fine motor skills according to the 5-15R questionnaire and QH-I scores.

Child's use of his or her hands	Correlation Coefficient[a]	p-value
Does not like to draw, has difficulty drawing figures that represent something	0.064	0.688
Difficulty handling, assembling, and manipulating small objects	0.063	0.693
Difficulty pouring water into a glass without spilling it	0.156	0.325
Often spills food onto clothes or table when eating	0.296	0.057
Difficulty using a knife and a fork	0.351	0.023
Difficulty buttoning or tying shoelaces	0.288	0.065
Difficulty using a pen (e.g., presses too hard, hand is shaking)	0.006	0.968
Has not developed a clear hand preference, i.e., is neither clearly right-handed nor left-handed	-0.114	0.473
Writing is slow and laborious	0.040	0.800
Immature pencil grip, holds the pen in an unusual manner	0.070	0.659

[a]Derived from Spearman's rho. Statistical significance set at $p < 0.05$.

Table 6. Fine motor skills associated with differences in Quigley-Hein Index (QH-I) scores before and after toothbrushing in unadjusted bivariate and adjusted multivariate regression.

Parameter	Mean difference in dental plaque score (B coefficient)			
	Unadjusted [95%CI]	p-value	Adjusted [95%CI]	p-value
(Intercept)			3.569 [2.150-4.987]	< 0.001
Boys (ref. girls)	-0.456 [-0.833 - -0.080]	0.017	-0.253 [-0.601-0.094]	0.153
Screwing the toothpaste top (ref. never/seldom)	-0.135 [-0.565-0.294]	0.536	0.189 [-0.224-0.602]	0.369
Palm-to-finger translation[a] (ref. never/seldom)	-0.018 [-0.472–0.436]	0.938	0.304 [-0.156-0.765]	0.195
Movements from hands[a] (ref. never/seldom)	-0.840 [-1.742–0.061]	0.068	-1.012 [-2.066-0.041]	0.060
Lateral movements[a] (ref. never/seldom)	-0.236 [-1.543–1.071]	0.723	0.961 [-0.535-2.457]	0.208
Up-down movements[a] (ref. never/seldom)	-0.089 [-0.623–0.446]	0.745	-0.235 [-0.670-0.200]	0.290
Age (*continuous*)	-0.240 [-0.396 - -0.094]	0.001	-0.315 [-0.481 - -0.148]	< 0.001
(Scale)			0.263 [0.172-0.404]	

A general linear model was estimated with the following variables: spiral drawing (Archimedes test); immature prehension patterns; inefficient prehension patterns; simple rotation; complex rotation; movements from the hands and forearms; movements from the hands, forearms and arms; contralateral movements; back-forward movements and spiral movements. Statistical significance set at $p < 0.05$; [a]Grabbing a toothbrush.

Ethics approval

We conducted this study according to the ethical guidelines for research involving human beings of the Declaration of Helsinki, and the study was approved by the Bioethics Committee at Universidad Cooperativa de Colombia (under process, No. 003-2018). Study permission and informed consent were provided by the principals of the primary schools and the parents, respectively.

Discussion

Fine motor activities require coordination of small muscles to enable precise movements, particularly of the hands and face. Generally, these skills include handwriting, drawing, cutting, and manipulating small objects,[32] such as a toothbrush. These skills have been related to the growth of intelligence in different stages of human development. We hypothesized that fine motor skills would be significantly associated with toothbrushing efficacy; based on our findings, we refuted this hypothesis.

First, FMS reflected by parental reporting in the present study mainly centered on activities such as drawing, writing, pen gripping, holding everyday objects, and problems with spilling liquid. Based on this, we found that 12% of the children would require further evaluation of their FMS, the limitations of which may be related to milder forms of cerebral palsy[33] or to ADHD.[21] In particular, we found a similar prevalence of FMS limitations when using the Archimedes test (spiral drawing). In our study, 31% of children presented limitations in the spiral drawings, 14% of them drew a line completely outside of the pattern (moderate tremor) as an indicator of poor hand motor function, and 17% displayed mild limitations only. Our prevalence was similar to that reported in a study from New York in the US,[34] which observed limitations in 35% of these categories. Notably, however, the distribution in severity was different, with 33% of children exhibiting mild FMS limitations and only 2% having more severe FMS limitations in the US study. Another study from Burgos, Spain[35] reported a higher prevalence of 54%, again with primarily mild (52%) and only a few (2%) moderate limitations. It is important to highlight that in both studies, older children aged 9 to 14 were assessed, and tests were conducted slightly differently, which may explain differences in the prevalence and severity distribution to some degree.

Second, we found specific FMS limitations relevant to toothbrushing, mostly those involving dissociative movements of the hand (a group of muscles are moving independently of others), that may lead to less precise movements. Additionally, up-down and spiral movements were affected; they are known to be relevant for certain toothbrushing techniques. For example, some children cleaned the lingual surfaces of their lower teeth by performing horizontal instead of up-down or spiraling movements, which require more complex neurodevelopment and training. The interactions between parents and children, as well as between teachers and children, seem relevant to train these movements; toothbrushing exercise may also be regarded as neurological training. Parent-led toothbrushing has been associated with lower odds of a child having a history of caries.[36] Most children's baseline dental plaque scores in the present study, however, implied that parents usually did not clean their children's teeth at all (or were inept at it, possibly as a sign of their own low health literacy); as a result, a high frequency of dental caries was observed.

Third, we noted a globally positive correlation between parents' perceptions of their children's FMS and dental plaque scores, and that daily activities such as *often spills food onto clothes or table when eating*, *difficulty using a knife and a fork*, and *difficulty buttoning or tying shoelaces* may increase this dental plaque score. These activities may be related to dyspraxia. It is defined as "a breakdown of praxis [action]" and "the inability to utilize voluntary motor abilities effectively in all aspects of life from play to structured skilled tasks"[37] that may involve a developmental coordination disorder.[38] Furthermore, if a child has dyspraxia, he or she may also present with other conditions, such as ADHD[39] or dyslexia.[38] Prehension patterns used in knives and forks may be similar to some appropriate patterns utilized in toothbrushing. In addition, the presence of clumsiness or inaccurate movements in fine motor functions, measured through spilling food onto clothes or the table, or buttoning or tying shoelaces, may be important indicators of toothbrushing efficacy. This is because toothbrushing requires accurate force control and finger grip. Remarkably, we did not find activities related to learning, such as drawing, or slow and laborious writing or using a pen, to be correlated with toothbrushing efficacy.

We could not confirm a significant association between FMS and toothbrushing efficacy. Instead, we found that age was associated with better toothbrushing efficacy, which may be expected given the established relationship between age and neurodevelopment. However, the children in our sample were from a low-income background and may have suffered from childhood malnutrition,[40] continuous undernourishment, and associated neurodevelopmental deficits, including poor academic achievement and behavioral problems.[41] In such children, it might not be possible to relate toothbrushing efficacy to FMS given the characteristics of their neurodevelopment. Moreover, toothbrushing efficacy might not depend on these skills alone, as one might expect in regard to an association between toothbrushing efficacy and FMS. For this reason, other components of fine motor control, such as grip force scaling, speed of movement, and motor coordination[42] should be evaluated.

Regarding grip force, for example, researchers[43] have identified a correlation between the coefficient of the variation in force and the number of force fluctuations per second with fine motor performance and normal dexterity in a handwriting task. Moreover, the better the muscle coordination and accurate force control used—not only in handwriting but also when children manipulate small objects (such as a toothbrush)— the more manual dexterity is increased. In addition, fingers are united into synergies during a production of force. In our study, children had different inefficient prehension patterns that may change toothbrush grip kinetics. Also, our sample presented with problems of coordination and visual-motor coordination that may influence the precision of dental plaque removal. Research on the production and fluctuation of force and speed of movements is also needed in teeth cleaning to clarify other aspects of the efficacy of toothbrushing performance.

In bivariate regression, boys showed higher toothbrushing efficacy. The literature provides evidence that males have a greater ability for motor skills such as aiming, catching, and throwing, whereas females are better at tasks where precision and fine hand ability are needed.[44] Consequently, boys may have more grip force than girls, leading to higher brushing efficacy. Some studies also suggest that force generation and relaxation are faster in males than females, and there are also differences in muscle fiber type composition between the sexes[45] that could be relevant in this activity, which could further contribute to sex-based differences in brushing efficacy in children. Notably, in multivariable analysis, this association with sex was not confirmed.

Limitations

First, we conducted a cross-sectional study; we cannot deduce any temporal trends or causal associations from it. Second, the sample was small and not randomly drawn but rather by convenience. It is prone to selection bias and might not show representativeness for the wider population. The limitations in sample size impact statistical power, which is why our finding of an absence of statistical associations should not be confused with no association at all. Remarkably, we detected a significant association between FMS and age, indicating that some statistical power is present. Larger studies may be needed to confirm our negative findings. Third, plaque scores might not comprehensively reflect tooth brushing movements only, but also brushing duration and systematic brushing.[46] Generally, plaque indices serve as proxies only, which can be easily measured but do not necessarily correspond to dental conditions.

Conclusions

In this study, FMS significantly increased with age, confirming the established relationship between age and neurodevelopment; however, these skills and toothbrushing efficacy were not significantly associated. For this reason, aspects such as grip force scaling, speed of movement, and motor coordination should be analyzed in more detail to improve our understanding of the kinetics of toothbrushing. Doctors and dentists should pay attention to FMS limitations in different age groups and address them by approaching and educating parents or referring them to specialist services.

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References

1. Bruininks RH, Bruininks BD. BOT2 Bruininks-Oseretsky Test of motor proficiency. Minneapolis: NCS Pearson; 2005.
2. Kelly DP, Natale MJ. Neurodevelopmental and executive function and dysfunction. In: Kliegman RM, St. Geme JW, Blum NJ, Shah SS, Tasker RC, Wilson KM, editors. Nelson textbook of pediatrics. 21st ed. Philadelphia: Elsevier; 2020. Chapter 48.
3. Pienaar AE, Barhorst R, Twisk JW. Relationships between academic performance, SES school type and perceptual-motor skills in first grade South African learners: NW-CHILD study. Child Care Health Dev. 2014 May;40(3):370-8. https://doi.org/10.1111/cch.12059
4. Carlson AG, Rowe E, Curby TW. Disentangling fine motor skills' relations to academic achievement: the relative contributions of visual-spatial integration and visual-motor coordination. J Genet Psychol. 2013 Sep-Dec;174(5-6):514-33. https://doi.org/10.1080/00221325.2012.717122
5. Wehby GL, Prater K, McCarthy AM, Castilla EE, Murray JC. The impact of maternal smoking during pregnancy on early child neurodevelopment. J Hum Cap. 2011;5(2):207-54. https://doi.org/10.1086/660885

6. Patil SP, Patil PB, Kashetty MV. Effectiveness of different tooth brushing techniques on the removal of dental plaque in 6-8 year old children of Gulbarga. J Int Soc Prev Community Dent. 2014 May;4(2):113-6. https://doi.org/10.4103/2231-0762.138305
7. Kumar S, Tadakamadla J, Johnson NW. Effect of toothbrushing frequency on incidence and increment of dental caries: a systematic review and meta-analysis. J Dent Res. 2016 Oct;95(11):1230-6. https://doi.org/10.1177/0022034516655315
8. Trinh VA, Tarbit E, Do L, Ha D, Tadakamadla SK. The influence of family socioeconomic status on toothbrushing practices in Australian children. J Public Health Dent. 2021 Dec;81(4):308-15. https://doi.org/10.1111/jphd.12477
9. Gill P, Stewart K, Chetcuti D, Chestnutt IG. Children's understanding of and motivations for toothbrushing: a qualitative study. Int J Dent Hyg. 2011 Feb;9(1):79-86. https://doi.org/10.1111/j.1601-5037.2010.00442.x
10. Colaizzi LR, Tomar SL, Urdegar SM, Kass SH. Does the structure of dental hygiene instruction impact plaque control in primary school students? J Dent Hyg. 2015 Jun;89(3):180-9.
11. Mescher KD, Brine P, Biller I. Ability of elementary school children to perform sulcular toothbrushing as related to their hand function ability. Pediatr Dent. 1980 Mar;2(1):31-6.
12. Berzinski M, Morawska A, Mitchell AE, Baker S. Parenting and child behaviour as predictors of toothbrushing difficulties in young children. Int J Paediatr Dent. 2020 Jan;30(1):75-84. https://doi.org/10.1111/ipd.12570
13. Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. J Clin Epidemiol. 2008 Apr;61(4):344-9. https://doi.org/10.1016/j.jclinepi.2007.11.008
14. Colombia. Resultados censo nacional de población y vivienda 2018. DANE. 2019 June 26 [cited 2021 Feb 1]. Available from: https://www.dane.gov.co/files/censo2018/informacion-tecnica/presentaciones-territorio/190726-CNPV-presentacion-Narino-Pasto.pdf
15. Minsalud (CO). Balance proceso reglamentario. 2017 [cited 2020 Oct 5]. Available from: https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/DE/PS/documento-balance-1618-2013-240517.pdf
16. Quigley GA, Hein JW. Comparative cleansing efficiency of manual and power brushing. J Am Dent Assoc. 1962 Jul;65(1):26-9. https://doi.org/10.14219/jada.archive.1962.0184
17. Turesky S, Gilmore ND, Glickman I. Reduced plaque formation by the chloromethyl analogue of victamine C. J Periodontol. 1970 Jan;41(1):41-3. https://doi.org/10.1902/jop.1970.41.1.41
18. Bass CC. An effective method of personal oral hygiene. J La State Med Soc. 1954 Feb;106(2):57-73.
19. Fones AC. Mouth hygiene. 4th ed. Philadelphia: Lea & Febiger; 1934.
20. Boyce W, Gowland C, Rosenbaum P, Hardy S, Lane M, Plews N, et al. Gross motor performance measure manual. Kingston: Queen's University; 1999.
21. Kadesjö B, Janols LO, Korkman M, Mickelsson K, Strand G, Trillingsgaard A, et al. The FTF (Five to Fifteen): the development of a parent questionnaire for the assessment of ADHD and comorbid conditions. Eur Child Adolesc Psychiatry. 2004;13 Suppl 3:3-13. https://doi.org/10.1007/s00787-004-3002-2
22. Korkman M, Jaakkola M, Ahlroth A, Pesonen AE, Turunen MM. Screening of developmental disorders in five-year-olds using the FTF (Five to Fifteen) questionnaire: a validation study. Eur Child Adolesc Psychiatry. 2004;13(S3 Suppl 3):31-8. https://doi.org/10.1007/s00787-004-3005-z
23. Rodríguez-Pérez C, Nicasio García J. Validación y utilización empírica de un instrumento de diagnóstico en una muestra de niños con el Trastorno por Déficit de Atención con y sin Hiperactividad (TDAH): el cuestionario Five to Fifteen (FTF). Int J of Dev Educ Psychol. 2008;1(3):241-9.
24. Beltrán-Ortiz MF, Barra HT, Franzani P, Martinich C, Castillo RD. [The Five to Fifteen Questionnaire (FTF) for a comprehensive assessment of development: psychometric properties and characterization of a sample of Chilean children]. Ter Psicol. 2012;30(3):31-47. Spanish. https://doi.org/10.4067/S0718-48082012000300004
25. Trouillas P, Takayanagi T, Hallett M, Currier RD, Subramony SH, Wessel K, et al. International Cooperative Ataxia Rating Scale for pharmacological assessment of the cerebellar syndrome. J Neurol Sci. 1997 Feb;145(2):205-11. https://doi.org/10.1016/S0022-510X(96)00231-6
26. Hoogendam YY, Lijn F, Vernooij MW, Hofman A, Niessen WJ, Lugt A, et al. Older age relates to worsening of fine motor skills: a population-based study of middle-aged and elderly persons. Front Aging Neurosci. 2014 Sep;6:259. https://doi.org/10.3389/fnagi.2014.00259
27. Schneck CM, Henderson A. Descriptive analysis of the developmental progression of grip position for pencil and crayon control in nondysfunctional children. Am J Occup Ther. 1990 Oct;44(10):893-900. https://doi.org/10.5014/ajot.44.10.893
28. Dennis JL, Swinth Y. Pencil grasp and children's handwriting legibility during different-length writing tasks. Am J Occup Ther. 2001 Mar-Apr;55(2):175-83. https://doi.org/10.5014/ajot.55.2.175
29. Exner CE. In-hand manipulation skills. In: Case-smith J, Pehoski C, editors. Development of hand skills in the child. Bethesda: American Occupational Therapy Association; 1992. p. 35-40.
30. Exner CE. Content validity of the in-hand manipulation test. Am J Occup Ther. 1993 Jun;47(6):505-13. https://doi.org/10.5014/ajot.47.6.505
31. Case-Smith J, O'Brien JC. Occupational therapy for children. 6th ed. Missouri: Mosby Elsevier; 2010. p. 275-312.

32. American Psychological Association. Fine motor. Washington: American Psychological Association; 2021 [cited 2021 Feb 20].Available from: https://dictionary.apa.org/fine-motor
33. Forsman L, Eliasson AC. Strengths and challenges faced by school-aged children with unilateral CP described by the Five To Fifteen parental questionnaire. Dev Neurorehabil. 2016 Dec;19(6):380-8. https://doi.org/10.3109/17518423.2015.1017662
34. Louis ED, Garcia WE, Rauh VA. Tremor in a population-based cohort of children in New York City. Pediatr Neurol. 2015 Feb;52(2):187-91. https://doi.org/10.1016/j.pediatrneurol.2014.10.017
35. Louis ED, Cubo E, Trejo-Gabriel-Galán JM, Villaverde VA, Benito VD, Velasco SS, et al. Tremor in school-aged children: a cross-sectional study of tremor in 819 boys and girls in Burgos, Spain. Neuroepidemiology. 2011;37(2):90-5. https://doi.org/10.1159/000330352
36. Collett BR, Huebner CE, Seminario AL, Wallace E, Gray KE, Speltz ML. Observed child and parent toothbrushing behaviors and child oral health. Int J Paediatr Dent. 2016 May;26(3):184-92. https://doi.org/10.1111/ipd.12175
37. Bowens A, Smith I. Childhood dyspraxia: some issues for the NHS. Nuffield Institute for Health; 1999. Nuffield Portfolio Programme Report No: 2 Leeds.
38. Gibbs J, Appleton J, Appleton R. Dyspraxia or developmental coordination disorder? Unravelling the enigma. Arch Dis Child. 2007 Jun;92(6):534-9. https://doi.org/10.1136/adc.2005.088054
39. Farmer M, Echenne B, Drouin R, Bentourkia M. Insights in developmental coordination disorder. Curr Pediatr Rev. 2017;13(2):111-9. https://doi.org/10.2174/1573396313666170726113550
40. Colombia. DNP. Primero las niñas y los niños: desarrollo integral desde la primera infancia hasta la adolescência. 2019 [cited 2021 Mar 2]. Available from: https://www.dnp.gov.co/DNPN/Plan-Nacional-de-Desarrollo/Paginas/Pilares-del-PND/Equidad/Primero-las-ninas-y-los-ninos.aspx
41. Galler JR, Koethe JR, Yolken RH. Neurodevelopment: The Impact of Nutrition and Inflammation During Adolescence in Low-Resource Settings. Pediatrics. 2017 Apr;139 Suppl 1:S72-84. https://doi.org/10.1542/peds.2016-2828I
42. Burr P, Choudhury P. Fine motor disability. StatPearls. Treasure Island: StatPearls; 2021.
43. Lin YC, Chao YL, Wu SK, Lin HH, Hsu CH, Hsu HM, et al. Comprehension of handwriting development: pen-grip kinetics in handwriting tasks and its relation to fine motor skills among school-age children. Aust Occup Ther J. 2017 Oct;64(5):369-80. https://doi.org/10.1111/1440-1630.12393
44. Liutsko L, Muiños R, Tous Ral JM, Contreras MJ. Fine motor precision tasks: sex differences in performance with and without visual guidance across different age groups. Behav Sci (Basel). 2020 Jan;10(1):36. https://doi.org/10.3390/bs10010036
45. Haizlip KM, Harrison BC, Leinwand LA. Sex-based differences in skeletal muscle kinetics and fiber-type composition. Physiology (Bethesda). 2015 Jan;30(1):30-9. https://doi.org/10.1152/physiol.00024.2014
46. Silvestrini Biavati A, Gastaldo L, Dessì M, Silvestrini Biavati F, Migliorati M. Manual orthodontic vs. oscillating-rotating electric toothbrush in orthodontic patients: a randomised clinical trial. Eur J Paediatr Dent. 2010 Dec;11(4):200-2.