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Toothbrushing Performance and Oral Cleanliness after Brushing in 12-Year-Old Children

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Abstract: ***Objectives:*** *Nationwide prevention programs in Germany aim to promote oral health. The group prevention program starts in kindergarten and ends when the children are about 12 y old. While in a recent study, toothbrushing behavior of 12-y-old children was analyzed, the present study's objective was to examine the children's ability to achieve oral cleanliness and to analyze how toothbrushing behavior and compliance with the toothbrushing recommendations taught in the group prevention programs predict oral cleanliness.*

Methods: *Twelve-year-old randomly selected children (*N = 174*) were asked to brush their teeth to the best of their abilities, and simultaneously a video was recorded for behavioral analyses. Plaque levels were measured before and immediately after toothbrushing. In addition, dental status and gingival bleeding were assessed.*

Results: *After brushing to the best of their abilities, there was plaque on 50% (±24.72%) of all measured sites at the gingival margin (Marginal Plaque Index). Regression analyses revealed approximately 22% of the variance of marginal plaque on the outer surfaces to be explained by the time brushed by circular movements ($\beta = -0.41$; $P < 0.001$) and the number of sextants brushed for at least 7.5 s ($\beta = -0.171$; $P < 0.05$). Circular movements explained most additional variance ($\Delta R^2 = 0.113$; $P < 0.001$). With respect to inner surfaces, none of the behavioral aspects explained any variance of oral cleanliness.*

Conclusion: *Despite regular group prevention measures, 12-y-old children show limited skills to clean their teeth adequately. Furthermore, none of the recommended behaviors relates to oral cleanliness after toothbrushing at inner surfaces. As a consequence, it is necessary to explore further which behavioral sequences effectively improve oral cleanliness.*

Knowledge Transfer Statement: *This study illustrates that children's compliance to toothbrushing recommendations is not necessarily related to toothbrushing effectiveness. Clinicians should therefore assess the effectivity of recommendations individually and provide individual guidance for improvement.*

Keywords: oral hygiene, tooth brushing, gingivitis, behavioral science, child dentistry, preventive dentistry

Introduction

Prevention of oral diseases like caries, gingivitis, and periodontitis strongly depends on the efficiency of daily oral hygiene (Gibson and Williams 1999; Marinho et al. 2003; Marinho et al. 2004; Lam 2014). Beginning with the emergence of the first tooth, it is necessary to remove plaque deposits on a daily basis (Ismail 1998; Sgan-Cohen 2005). In early childhood, this has to be done by the parents (Aunger 2007; Benadof et al. 2015; Collett et al. 2016). The actual guideline of the European Society of Pediatric Dentistry

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A supplemental appendix to this article is available online.

recommends "twice daily use of fluoride toothpaste, in combination with oral hygiene instructions, is the cornerstone of any preventive program for children, irrespective of caries risk" (Toumba et al. 2019). That shows the importance of a clean surface for every preventive program in pediatric dentistry. However, the older the children get, the more they have to take responsibility themselves for oral hygiene (Baric et al. 1974). It is thus inevitable to empower them to do so (Jong-Lenters et al. 2014; Freeman 2015; Virgo-Milton et al. 2016). Yet, scientific evidence is missing, which would be the most efficient strategy of oral hygiene training (Muller-Bolla et al. 2011; Baehni 2012; Cooper et al. 2013; Habbu and Krishnappa 2015). Furthermore, recent studies of young adults indicate that despite all endeavors to train them with proper oral hygiene skills, they still are unable to establish oral cleanliness, even when they perform oral hygiene to the best of their abilities (Harnacke, Beldoch, et al. 2012; Harnacke, Mitter, et al. 2012; Deinzer et al. 2014; Harnacke et al. 2015; Deinzer et al. 2018; Ebel et al. 2019; Petker et al. 2019).

A recent study analyzed whether children practice what they had been taught regarding oral hygiene (Deinzer et al. 2019). This study examined German children who had just passed a group prevention program that starts at kindergarten and ends usually at the sixth grade, when the children are 12 y old (Arbeitsgemeinschaft der Spitzenverbände der Krankenkassen 2000; Reich 2001). In this group prevention program, children are trained to brush their teeth systematically in order to brush all the teeth and surfaces for a reasonable period of time. Furthermore, they learn to brush their outer surfaces by circular movements and their inner surfaces by vertical movements. Horizontal brushing movements are only intended for the occlusal surfaces (Deinzer et al. 2019). Despite these clear instructions, which are supported by a publicly available brushing song and are to be used while toothbrushing at home (Zahnputz-Zauber 2012; Thumeyer 2015), most children do not show the behaviors requested. Even when they are asked to brush their teeth to the best of their abilities, they tend to neglect inner surfaces and to brush their inner and outer surfaces often by other movements than those trained (Deinzer et al. 2019).

Collectively, these studies indicate that children have low efficiency to adopt the toothbrushing recommendations given to them. The present analysis therefore further investigates the relationship between specific aspects of children's toothbrushing performance and the degree of oral cleanliness they achieve after brushing. It describes in detail the clinical data of the children. In particular, it analyzes the degree of oral cleanliness they achieved after oral hygiene. Furthermore, it relates aspects of toothbrushing performance to this degree of oral cleanliness. Finally, it assesses whether and to what degree children's compliance with the recommendations named above predicts oral cleanliness. The purpose of these analyses is to obtain further indications as to which aspects of toothbrushing behavior are particularly important, which may be of less importance, and to suggest the necessary future research.

The present research thus aims to answer the following questions:

- What degree of oral cleanliness do children achieve when they perform oral hygiene to the best of their abilities?
- Which aspects of toothbrushing behavior predict oral cleanliness after toothbrushing best?
- How does the degree of compliance children demonstrate regarding toothbrushing recommendations relate to oral cleanliness they achieve after toothbrushing?

Methods

Ethics Approval

This study was conducted according to the principles of the Declaration of Helsinki and was approved by the local Ethics Committee of the medical faculty of the University of Giessen (AZ 42/13). All participants and their parents provided informed written consent.

Participants

As the detailed methodology of this study has been published earlier (Deinzer et al. 2019), the following description focuses only on the core aspects relevant to the current analysis. For additional details, see Deinzer et al. (2019).

The target group for the present analysis were children at the end of the group prevention programs for oral health. These programs begin when the children are in kindergarten and end usually at the age of 12 y. Participants were eligible for participation when they were 12 y old at the time of study conduction and when they brushed their teeth habitually by the use of manual toothbrushes. They were excluded when they had fixed orthodontic appliances or cognitive or physical impairments that affected toothbrushing. A total of 174 children were analyzed. A flow diagram illustrating participants' recruitment can be found in the previous publication (Deinzer et al. 2019).

General Design

The group prevention programs include oral hygiene instructions, which are given by a specially developed brushing song (Zahnputz-Zauber 2012; Thumeyer 2015). The song instructs the children to brush their occlusal surfaces by horizontal scrubbing, the inner surfaces by vertical strokes, and the outer surfaces by circular movements while jaws are closed (tiger bite). The brushing time in the song is 7.5 s per sextant for the inner surfaces, 7.5 s per antagonistic sextants for the outer surfaces, and 7.5 s per quadrant for the occlusal surfaces (see Deinzer et al. 2019). These instructions form the basis of the former and current analyses.

Children were asked to participate without brushing their teeth for at least

4 h before the start of this study. Dental status was first assessed, followed by the assessment of plaque and gingival bleeding. Then, children were asked to brush their teeth to the best of their abilities with a standard manual toothbrush (Deinzer et al., 2012) provided with a single-use brush head (Braun Oral-B Pulsonic) and toothpaste (Elmex Junior). Brushing behavior was recorded on a tablet computer, which also served as a mirror. While brushing, the children were left alone. Immediately after brushing, plaque was assessed once again. Clinical examination was completed by the assessment of the DMFS (decayed, missing, filled surfaces).

Observed Oral Hygiene Behavior

Brushing videos were analyzed by calibrated observers using the video analysis software (Interact 14; Mangold International). For details of the calibration procedure and the observation method, see Deinzer et al. (2019) and Appendix. The present analyses focus on inner and outer surfaces (as plaque is only measured at these surfaces). The following general aspects of brushing behavior and aspects indicating the degree of compliance with the instructions taught by the brushing song were analyzed separately for inner and outer surfaces, respectively:

General behavior aspects:

- Brushing duration (i.e., total time of contact of the bristles to the teeth) on the inner and outer surfaces, respectively
- Duration of horizontal brushing movements
- Duration of vertical brushing movements
- Duration of circular brushing movements
- Duration of time spent without movements while the bristles were in contact with the teeth (these 4 codings of movements add to the total brushing time)
- Number of sextants brushed for at least 7.5 s

Aspects indicating the degree of compliance:

- Percentage of time inner surfaces were brushed by vertical movements
- Percentage of time outer surfaces were brushed by circular movements
- Number of inner sextants that were brushed for at least 7.5 s
- Number of outer sextants that were brushed for at least 7.5 s
- Percentage of time by which outer surfaces were brushed with mandibles closed (tiger bite)

Clinical Assessment

Two calibrated dental examiners (O.C., J.W.) performed clinical assessment (dental status, gingival inflammation, and plaque). For calibration, individuals not involved in the present study were analyzed by the dental examiners and by an experienced (already calibrated) dentist. Calibration criterion was an agreement of >90% for the 5 consecutive individuals and no disagreement by >1 degree of scoring.

Dental plaque was disclosed by a fluorescent staining solution (Plaque Test; Ivoclar Vivadent), which is only visible under black light. Thus, plaque was invisible for the children. Scoring of plaque was done both on the inner and outer surfaces of all teeth present by the Marginal Plaque Index (MPI; Deinzer et al. 2014), which is the primary outcome variable, and the Turesky modification of the Quigley and Hein Index (TQHI; Turesky et al. 1970).

The MPI assesses in detail the plaque adjacent to the gingival margin. Briefly, the gingival margin of the tooth (inner or outer site) is divided into 4 sections of equal size, and the presence (score 1) or absence (score 0) of plaque is recorded. Thus, for each tooth, 8 scores were recorded.

The TQHI assesses distribution of plaque over the crown. Its scores are as follows:

1. 0: no plaque
2. 1: flecks of stain at the gingival margin
3. 2: definite line of plaque at the gingival margin
4. 3: gingival third of surface
5. 4: two-thirds of surface
6. 5: greater than two-thirds of surface

As a measure of dental status, the number of surfaces with untreated caries, initial caries, and secondary caries, filled and sealed were assessed on all permanent teeth. In the present sample, no child had lost a permanent tooth due to caries.

As an indicator of gingivitis, the papillary bleeding index (PBI; Saxer and Mühlemann 1975), modified by (Rateitschak et al. 1989), was assessed on all the teeth (both on the inner and outer sites). The scores are as follows:

1. 0: no bleeding
2. 1: single bleeding point(s)
3. 2: several bleeding points or thin line
4. 3: interdental triangle filled with blood
5. 4: profound bleeding

Statistics

All statistical analyses were computed using IBM SPSS Statistics 26 (SPSS, Inc.). All variables were tested for normal distribution by the Kolmogorov-Smirnov goodness-of-fit test. The primary outcome variable was the MPI.

Descriptive analyses of plaque indices after brushing were computed to answer the first research question. Furthermore, comparisons between plaque prior to and after brushing were computed by paired *t* test or Wilcoxon tests depending on the distribution of the parameters.

For the second and third research questions (relationship between general aspects of behavior and compliance aspects with plaque), regression analyses were computed with the criterion variables MPI (percentage of sections with plaque) and TQHI (mean score), respectively. The MPI was the primary criterion variable as it has been shown to be more sensitive to differences in oral hygiene behavior (Deinzer et al. 2014). Separate analyses were computed for inner and outer surfaces, since

toothbrushing instructions differed for these surfaces. Participants with leverage values exceeding the limit suggested by Igo (2010) were excluded from analyses to prevent distortion of the equation by outlying values in the predictor variables. Afterward, analyses were reestimated and participants with absolute levels of studentized residuals exceeding 2 (stud. res. >|2|) were excluded to prevent distortion of the equation by outlying values in the criterion variable. To control for distortions due to multicollinearity, only variables with variance inflation factor values below 10 remained in the final equation. A visual inspection of the residual scatterplot and the p-p plot was performed to assess homoscedasticity and normal distribution of the residuals, respectively.

To answer the second research question (which general behavioral aspects predict oral cleanliness after thorough brushing the best), the abovementioned general brushing parameters were included as predictors into a backward regression analysis with $P < 0.05$ as inclusion and $P > 0.1$ as exclusion criterion for a parameter. To avoid multicollinearity, the total duration of brushing time was not included into these analyses (as this equals the sum of the duration of the brushing movements).

Hierarchical regression analyses (2 steps each) addressed the third research question. For each compliance parameter, it was analyzed by how much it contributes to variance explanation (step 2) after all other compliance parameters and total brushing time had been taken into account in step 1.

The study conforms to STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.

Results are displayed in tables; corresponding figures are provided in the Appendix.

Results

Descriptive Data

In total, 174 children (n = 83 female/ n = 91 male) provided data for this analysis. At the time of study conduction, all children were 12 y old. They had a mean number of 22.7 permanent teeth (minimum = 12; maximum = 28); the mean total number of teeth was 24.6 (minimum = 18; maximum = 28). Twenty-three had at least 1 decayed surface, 38 had filled surfaces (plus 1 filled with decay), and 47 showed initial caries (for details regarding the DMFS, see the Appendix). Of the children, 9.8% showed no papillary bleeding at all, and 46.6% showed papillary bleeding at less than 10% of all sites. Thereby, PBI data are strongly skewed (see the Appendix). The majority of the children (n = 123) children had at least 1 parent with a university entrance diploma. No information was available regarding the educational status of the parents of 7 children.

Table 1.
Percentage of Children Brushing the Respective Number of Sextants for at Least 7.5 s.

Number of Sextants	Outer Surfaces	Inner Surfaces
	Percentage of Children (n = 174)	
0	0.6	48.9
1	0.6	6.9
2	3.4	12.6
3	3.4	9.8
4	8.0	8.6
5	6.9	6.3
6	77.0	6.9

Toothbrushing Behavior

The mean numbers of sextants children brushed by more than 7.5 s with respect to the outer and inner surfaces were 5.5 ± 1.2 and 1.7 ± 2.0, respectively. Table 1 shows this aspect of compliance in detail. Children adhered to the advice to brush their outer surfaces by closing their jaws for 75.7% ± 26.5% of the total brushing time of the outer surfaces (i.e., 64.97 ± 43.2 s). The total time and the percentage of time by which children brushed their outer surfaces with circular movements and their inner surfaces with vertical movements and which other movements were applied are given in Table 2. For further details of brushing behavior less relevant for the present analysis, see Deinzer et al. (2019).

Degree of Oral Cleanliness after Brushing

Table 3 shows descriptive data of MPI and TQHI values before and after brushing. Comparison of plaque levels before and after brushing revealed significant differences for all MPI and TQHI values (all $P < 0.001$). Table 4 shows MPI values assessed after brushing at outer and inner surfaces on posterior and anterior sextants and the respective brushing time.

Prediction of Oral Cleanliness by Toothbrushing Behavior

With respect to outer surfaces, the regression models explained 22% of variance of MPI values ($F = 21.84$, $P < 0.001$, $R^2 = .23$, adjusted $R^2 = .22$) and 19% of variance of TQHI values ($F = 17.91$, $P < 0.001$, $R^2 = .20$, adjusted $R^2 = .19$). Significant predictor variables were duration of circular movements (MPI: $\beta = -.41$, $P < 0.001$; TQHI: $\beta = -.35$, $P < 0.001$) and number of sextants brushed for at least 7.5 s (MPI: $\beta = -.17$, $P = 0.03$; TQHI: $\beta = -.20$, $P = 0.02$).

With respect to inner surfaces, 28 children did not brush them at all. Comparing these children (n = 28) with children who brushed their inner surfaces

Table 2.
Distribution of Brushing Movements at Outer and Inner Surfaces.

Characteristic	Outer Surfaces (n = 174)		Inner Surfaces (n = 146)[a]	
	Mean (SD), s	Mean (SD), %	Mean (SD), s	Mean (SD), %
Horizontal movements	31.8 (29.4)	38.8 (30.4)	11.6 (18.0)	37.2 (38.8)
Circular movements	43.9 (37.6)	50.9 (32.4)	0.5 (3.2)[b]	1.0 (6.9)[b]
Vertical movements	7.9 (17.8)	8.3 (14.7)	25.5 (28.1)	58.9 (39.1)
No movements	1.7 (2.5)	1.9 (2.2)	0.8 (1.8)	2.8 (9.6)

[a]Not including those 28 children who did not brush their inner surfaces at all.
[b]Only 4 children showed circular movements at inner surfaces.

Table 3.
Descriptive Data of Plaque Levels (MPI and TQHI) before and after Brushing.

MPI (%)	Before Brushing[a]				After Brushing			
	Median	Q1	Q3		Mean	SD	SEM	95% CI
All surfaces	79.0	57.11	94.70		49.8	24.7	1.9	46.05–53.45
Outer surfaces	86.3	58.60	100.00		45.3	26.1	2.0	41.37–49.19
Inner surfaces	75.5	51.02	100.00		54.2	28.2	2.1	50.01–58.44
Cervical sections	73.0	48.58	91.96		44.9	25.1	1.9	41.14–48.64
Proximal sections	84.0	63.58	98.39		54.6	26.0	2.0	50.73–58.50
TQHI (mean)	**Mean**	**SD**	**SEM**	**95% CI**	**Mean**	**SD**	**SEM**	**95% CI**
All surfaces	1.8	0.6	0.1	1.69–1.88	1.2	0.7	0.0	1.07–1.23
Outer surfaces	2.0	0.8	0.1	1.86–2.10	1.1	0.6	0.1	0.98–1.17
Inner surfaces	1.6	0.6	0.1	1.50–1.69	1.2	0.6	0.1	1.13–1.32

MPI, Marginal Plaque Index; Q1, 25th percentile; Q3, 75th percentile; SEM, standard error of the mean; TQHI, Turesky modification of the Quigley and Hein Index.
[a]Due to skewed data, MPI values assessed before brushing are reported as median and interquartile range.

(n = 146) revealed a significant group difference (P = 0.027) with lower MPI values in those who brushed. Regression analysis for inner surfaces including only those children who brushed their inner surfaces revealed no significant explanation of variance either for the MPI (R^2 = 0.00) or for the TQHI (R^2 = 0.00).

Relationship between the Degree of Compliance Children Demonstrated with Respect to Toothbrushing Behavior and Achieved Oral Cleanliness after Brushing

Regarding outer surfaces, total brushing time and the 3 compliance parameters (percent brushing with mandibles closed, percent brushing with circular movements, and number of sextants brushed at least 7.5 s) explained together 25.6% of variance in the MPI (R^2 = 27.7; adjusted R^2 = 25.6; F = 13.379; P < 0.001) and 23.3% of variance in the TQHI (R^2 = 25.5; adjusted R^2 = 23.3; F = 11.737; P < 0.001). The bivariate correlations of these parameters with each other are illustrated in the Appendix. Table 5 shows the results of 3 hierarchical regression models. These analyzed the additional contribution to explain variance by 1 compliance parameter (step 2) to that of the other parameters and total brushing time (step 1).

With respect to inner surfaces, only 146 children who brushed their inner surfaces were included into analyses. The total brushing time and the 2 compliance parameters (percent brushing with vertical movements and number of sextants brushed by at least 7.5 s) did not explain variance of the MPI (R^2 = 0.04, adjusted R^2 = 0.02) or TQHI (R^2 = 0.03, adjusted R^2 = 0.01) on the inner surfaces. No further hierarchical analyses were thus computed.

Additional exploratory analysis of only those children who brushed all inner sextants for at least 7.5 s (n = 12) and thus showing complete compliance

Table 4.
Descriptive Data of Brushing Time of Posterior and Anterior Sextants and the Respective Plaque Levels (MPI) Assessed after Brushing at Outer and Inner Surfaces.

Characteristic	Brushing Time, s		MPI (%) after Brushing	
	Median (Q1; Q3)	Mean (SD; SEM; 95% CI)	Median (Q1; Q3)	Mean (SD; SEM; 95% CI)
Outer surfaces				
Sextant 1	10.4 (6.0; 15.5)	11.7 (7.7; 0.6; 10.57–12.89)	41.7 (16.7; 67.2)	45.5 (32.6; 2.5; 40.61–50.38)
Sextant 2	15.4 (10.6; 22.9)	18.6 (12.5; 0.9; 16.69–20.43)	41.7 (20.0; 75.0)	47.9 (33.1; 2.5; 42.92–52.83)
Sextant 3	9.2 (5.5; 14.4)	10.8 (7.0; 0.5; 9.70–11.80)	50.0 (25.0; 75.0)	50.3 (30.9; 2.3; 45.63–54.87)
Sextant 4	9.9 (6.7; 14.9)	11.8 (7.7; 0.6; 10.69–13.00)	50.0 (25.0; 81.3)	51.4 (34.1; 2.6; 46.33–56.54)
Sextant 5	16.8 (11.6; 25.1)	20.2 (23.0; 1.0; 18.23–22.12)	33.3 (8.3; 58.3)	37.1 (32.2; 2.4; 32.28–41.91)
Sextant 6	10.2 (6.6; 15.7)	12.4 (8.7; 0.7; 11.08–13.68)	37.7 (12.5; 68.8)	43.6 (32.8; 2.5; 38.65–48.47)
Inner surfaces				
Sextant 1	2.8 (0.0; 7.8)	4.8 (5.5; 0.4; 3.98–5.62)	66.7 (25.0; 100.0)	62.0 (37.1; 2.8; 56.47–67.55)
Sextant 2	4.2 (0.0; 9.1)	6.2 (7.5; 0.6; 5.09–7.34)	33.3 (8.3; 71.9)	41.6 (37.0; 2.8; 36.08–47.15)
Sextant 3	3.1 (0.0; 6.9)	4.4 (5.4; 0.4; 3.53;–5.16)	50.0 (18.8; 100.0)	54.3 (37.3; 2.8; 48.76–59.91)
Sextant 4	3.8 (0.1; 8.5)	5.7 (6.9; 0.5; 4.65–6.72)	93.8 (50.0; 100.0)	74.1 (31.6; 2.4; 69.40–78.85)
Sextant 5	3.3 (0.1; 9.2)	5.5 (6.3; 0.5; 4.50–6.40)	29.6 (0.0; 70.8)	38.7 (37.5; 2.8; 33.08–44.31)
Sextant 6	3.7 (0.0; 9.6)	5.7 (6.4; 0.5; 4.77–6.69)	93.8 (65.6; 100.0)	77.8 (29.1; 2.2; 73.40–82.11)

MPI, Marginal Plaque Index; Q1, 25th percentile; Q3, 75th percentile; SEM, standard error of the mean.

with respect to this brushing parameter revealed no significant correlation (r = 0.17; P = 0.59) between the plaque after brushing at the inner surfaces (MPI) and the time spent with vertical brushing movements (see Appendix).

Discussion

As expected, there were low scores of DMFS and PBI among the 12-y-old children in our study. Only 12% had 1 or more filled or decayed teeth, and more than 50% showed no or minimal bleeding. However, the plaque that remains especially after brushing underlines the importance of controlling the hygiene behavior to prevent oral health risks and to maintain oral health. Although most of the children managed to remove about 40% of plaque, there was plaque on 50% of the surfaces, even after brushing. Slot et al. (2012) reported similar results in their meta-analysis. The children in the present sample range at the lowest level of plaque reduction compared to the analyzed studies. This is remarkable as they were instructed to brush to the best of their abilities. In a former study, this instruction was found to go along with a longer brushing time compared to the instruction "brushing as usual" (Deinzer et al. 2018). Obviously, this effect was not followed by better results in oral cleanliness.

Consequently, it is necessary to consider in detail the relationship between aspects of brushing behavior and the persisting plaque after brushing.

Table 5.
Hierarchical Regression Analyses: Compliance Predicting Oral Cleanliness.

Step 1	Step 2	Criterion Variable (R^2 Change)	
		MPI	TQHI
Brushing duration **Time (%) of brushing with mandibles closed** **Brushing of vestibular sextants ≥7.5 s**	Time (%) of brushing by circular movements	0.113[a]	0.107[a]
Brushing duration **Time (%) of brushing with mandibles closed** **Time (%) of brushing by circular movements**	Brushing of vestibular sextants ≥7.5 s	0.021[b]	0.028[b]
Brushing duration **Brushing of vestibular sextants ≥7.5 s** **Time (%) of brushing by circular movements**	Time (%) of brushing with mandibles closed	0.032[b]	0.030[b]

R^2 change refers to the increment in variance explanation by the respective compliance parameter included in step 2 after controlling for variance explanation by the 2 other compliance parameters, respectively, plus total brushing time in step 1.
MPI, Marginal Plaque Index; TQHI, Turesky modification of the Quigley and Hein Index.
[a]$P < 0.001$.
[b]$P < 0.05$.

To understand systematics in this connection, outer and inner surfaces were differentiated. This is crucial as different brushing behavior is instructed for inner and outer surfaces. In addition, in the previous study (Deinzer et al. 2019), a substantial difference between brushing inner and outer surfaces concerning brushing movements and brushing time was actually detected.

For outer surfaces, the present regression analysis proves a significant contribution of circular movements followed by sufficient brushing time for all 6 segments in explaining the MPI variance. Overall, the explained variance exceeds that of other analyses referring to the whole mouth (Harnacke et al. 2015; Ebel et al. 2019). In these analyses, the abovementioned aspects of behavior were also found to be relevant. As circular movements for outer surfaces are taught in health care programs for children, the finding supports the relevance of this behavior for achieving cleanliness especially at the gingival margin, for which the MPI is a sensitive measure (Deinzer et al. 2014). Still, a considerable proportion of variance of the MPI was not explained by the present analysis. Potential reasons will be discussed below in the context of the findings for inner surfaces.

For inner surfaces, the results were far more complex. First, the likewise performed regression analysis revealed none of the general behavioral aspects to explain the plaque variance. To understand this finding, several additional steps were executed. Controlling the possibility that brushing inner surfaces may have no effect at all (as a consequence of inadequate brushing actions, for example), the difference in plaque after brushing between those 28 children who did not brush inner surfaces at all and the remaining 146 children who did was computed. Actually, children brushing inner surfaces showed lower plaque levels than children neglecting inner surfaces. This indicates that brushing does have an effect. However, variations in the MPI of these children were not predictable by general behavioral aspects or by their compliance with the instructions of the prevention program. A final step therefore analyzed only those 12 children who brushed each of all inner sextants at least 7.5 s (meaning minimum as long as taught). Within these children, the MPI was found to variate rather evenly between higher and lower grades, and there is no correlation between their brushing time by vertical movements and MPI. Therefore, the question about the relevant behavior elements for differences in plaque at inner surfaces remains unanswered.

In addition, a visual inspection of the relationship between the mean brushing time of posterior and anterior sextants and the respective plaque levels indicates that there appears to be no such relationship at inner or outer surfaces.

All these results show no connection between plaque and behavior regarding inner surfaces. Possible explanations for the lack of correlation between the analyzed elements of brushing behavior and plaque indicators are perhaps the behavioral aspects, which were not focused in this study. To remove plaque, additional to the type of brushing movements, pressure of brushing may be significant. Van der Weijden et al. (1998) showed a curvilinear relation between pressure and plaque removal. Also, the type of toothbrush (e.g., bristle stiffness) may contribute to efficient cleaning. Video analyses also do not allow for the observation of the precise location of the bristles with respect to the gingival margin, especially at inner surfaces. It is thus possible that children did not reach the marginal areas of the teeth while brushing, even when they performed the expected movements. Furthermore, finding systematic relationships requires

enough variance in time spent by brushing the inner surfaces, which was comparably shorter than that on the outer surfaces. Furthermore, a smaller sample size could be included in the analysis, as several children did not brush their inner surfaces at all. In young adults, a prediction of cleanliness on the inner surfaces by brushing movements proved to be successful (so far unpublished analysis by the authors). The present study is the first to describe in detail children's capability to achieve oral cleanliness and to relate this capability to behavioral aspects of toothbrushing. It further brings about important insights into which aspects of compliance with toothbrushing instructions relate strongest to plaque after brushing. It also demonstrates that regarding inner surfaces, the degree of compliance appears to be of no predictive value at all, at least in the present sample of 12-y-old children.

Future studies should prove the generalizability of this result as the present study underlies some limitations in this respect: although a large sample of children was included, the participants remained a selective group, as many randomly addressed families did not respond to the recruitment (see Deinzer et al. 2019). Self-selection favors children with interest in oral hygiene and perhaps with better skills. This could have resulted in overestimation of the brushing time or adequate brushing habits compared to an unselected group. As slightly different strategies in group prevention programs are used in various regions of Germany, the relation between instructions, brushing habits, and oral cleanliness may not apply to children in other areas. Therefore, these results cannot be generalized. Another limitation results from the cross-sectional design of the study, which assesses only the current degree of plaque distribution. The low prevalence of gingivitis might indicate that the plaque deposits assessed here did not persist long enough to induce gingivitis. Longitudinal studies are needed to further explore this point.

Conclusion

Despite regular group prevention measures, most children show limited skills to clean their teeth adequately. Their skills appear to be partly related to compliance with toothbrushing recommendations. Behavioral analyses within this study reveal that instructing the children to brush their outer surfaces of the teeth by circular movements for a fixed period of time (e.g., by means of a toothbrushing song) seems to be effective and reasonable to achieve oral cleanliness. However, for inner surfaces of the teeth, further analyses are necessary. The present analysis shows that none of the recommended behaviors relates to oral cleanliness after toothbrushing at inner surfaces. This dictates to explore further the behavioral sequences and their effectiveness on oral cleanliness.

Author Contributions

U. Weik, contributed to data analysis and interpretation, drafted and critically revised the manuscript; O. Cordes, contributed to data acquisition and analysis, critically revised the manuscript; J. Weber, contributed to data acquisition, critically revised the manuscript; N. Krämer, K. Pieper, contributed to conception, design, and data interpretation, critically revised the manuscript; J. Margraf-Stiksrud, contributed to conception, design, data analysis, and interpretation, drafted and critically revised the manuscript; R. Deinzer, contributed to conception, design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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