Toothbrushing and flossing habits in young adults – a video-based observational study

Inauguraldissertation

zur Erlangung des Grades eines Doktors der Zahnmedizin

des Fachbereichs Medizin

der Justus-Liebig-Universität Gießen

vorgelegt von Tobias Max Winterfeld

aus Wetzlar

Gießen 2014

Aus der

Poliklinik für Zahnerhaltungskunde und Präventive Zahnheilkunde

des Zentrums für Zahn-, Mund- und Kieferheilkunde

der Universitätsklinikum Gießen und Marburg GmbH

Standort Gießen

Leiter: Prof. Dr. Joachim Klimek

Gutachterin: Prof. Dr. Carolina Ganß

Gutachter: Prof. Dr. Uwe Gieler

Tag der Disputation: 22.07.2015

Für Ida

1 INTRODUCTION

There is no doubt that the removal of plaque from tooth surfaces is directly related to the prevention of caries, gingivitis and periodontitis. According to Charles C. Bass, *“[e]very person needs to keep his or her natural teeth healthy and normally functional throughout a potentially long life time.”* [1962]. Thus, regular oral hygiene is a prerequisite for the maintenance of the health of the teeth and periodontium [Loe et al., 1965;Axelsson and Lindhe, 1978;Lang et al., 1998]. Although many people report the regular performance of proper toothbrushing, the self-performed mechanical plaque removal is not often sufficiently effective [van der Weijden and Hioe, 2005]. Following the teaching and learning of toothbrushing, interproximal hygiene and the use of an effective brushing technique are mandatory. In addition, knowledge and understanding of one’s own oral hygiene situation is important. To achieve this goal, statutory health insurance funds are obliged to support and pay for dental services in the form of group prophylaxis and individual prophylaxis. This requirement has been anchored in German law since 1989 [Sozialgesetzbuch (SGB) Fünftes Buch (V), 2012a;Sozialgesetzbuch (SGB) Fünftes Buch (V), 2012b].

Health insurance funds, in cooperation with dentists and responsible institutions, are obligated to ensure group prophylaxis for people up to the age of 12 years (§21 section 1 and 2 SGB V), and insured individuals between 6 and 18 years of age are entitled to receive individual prophylaxis (§22 section 1 SGB V). Such preventive measures essentially consist of four different areas: the teaching of effective oral hygiene, nutrition advice for maintaining healthy teeth, professional fluoridation measures and fissure sealing [Pieper and Momeni, 2006].

In the state of Hesse, the ‘Landesarbeitsgemeinschaft für Jugendzahnpflege’ (LAGH) established guidelines for oral hygiene education [Landesarbeitsgemeinschaft für Jugendzahnpflege (LAGH), 2012]. These recommendations are considered part of group prophylaxis for oral hygiene education, with the goal of providing children with both an effective toothbrushing system and an effective brushing technique for life.

For children in particular, a special brushing system (the KAI system) was introduced and became widely accepted. According to this system, the occlusal tooth surfaces (Kauflächen ‘K’) should be brushed first, followed by the vestibular tooth surfaces (Außenflächen ‘A’) and, finally, the oral tooth surfaces (Innenflächen ‘I’) [Landesarbeitsgemeinschaft für Jugendzahnpflege (LAGH), 2012].

A child's physical development plays a decisive role in the learning of toothbrushing techniques. The physical stage of a child can be assessed by means of pictures painted by children in kindergarten [Thumeyer and Buschmann, 2012]. At this stage of development, motion sequences can be adapted to optimise brushing movements. The first drawings which were painted by children show lines running back and forth on the paper. The child paints mainly by moving the shoulder, resulting in a stiff wrist. At this stage, children can only perform large back-and-forth movements on the tooth surfaces. As physical development proceeds, the child will be able to brush first with large circular movements and, later, with smaller circular movements. Considering these facts, the LAGH developed and defined obligatory guidelines for brushing techniques in group prophylaxis: back-and-forth movements on occlusal surfaces, circular movements on vestibular surfaces and rolling movements on oral surfaces should be taught. Children in kindergarten and in the first and second grades of primary school should close their jaws and brush the vestibular surfaces of the teeth of both jaws together with large circles, according to the Fones technique [Fones, 1921;Hellwege, 1999]. Beginning in the third grade of primary school, the jaws should be opened and brushed separately using smaller circular movements.

Brushing duration plays an important role in effective toothbrushing (this means removing plaque) [Gallagher et al., 2009;Slot et al., 2012]; therefore, toothbrushing for at least 2 minutes is often recommended. An explicit duration is not provided by the LAGH, but some information can be inferred from the classification of 'brushing units'. For children in kindergarten, the occlusal tooth surfaces are divided into four brushing units (the right and left sides of both the lower and upper jaws). The vestibular tooth surfaces are divided into three units (closed jaws: anterior, left and right sides), and the oral surfaces are divided into six units (in each jaw: left side, anterior and right sides). In each unit, the brushing should take a defined time, which is determined by the duration of a specially developed KAI-toothbrushing song [Thumeyer, 2012]. This song consists of different verses concerning the person responsible for brushing (mother or father) and different choruses referring to the required movements in each area of the mouth. In parallel with the song, children should perform the intended movements in their own mouth. The KAI system should be used to ensure that all areas are reached with the toothbrush. The song can be played as long as necessary, meaning that the brushing duration is variable; however, the duration of the song is at least 2 minutes.

At the same time as group prophylaxis and as a continuation of it, an individually adapted brushing system and brushing technique should be implemented and trained. This is one of the major goals of individual prophylaxis.

In contrast to the above-mentioned precise guidelines for oral hygiene instructions in group prophylaxis, only general recommendations exist for individual prophylaxis [dos Santos et al., 2011], which could be related to the required individualised instruction, which is different for each individual. The Deutsche Gesellschaft für Zahn-, Mund- und Kieferheilkunde (DGZMK) states that no single brushing technique is specifically recommended [Dörfer et al., 2007]. Similarly, a review focusing on the effectiveness of different brushing techniques showed that none of the techniques appeared to be superior to the others with regard to plaque reduction [Muller-Bolla et al., 2011]. The sole recommendation provided by that review was to use a horizontal brushing technique in the temporary dentition.

The DGZMK [Dörfer et al., 2007] paid particular attention to the brushing system and the complete achievement of brushing all tooth surfaces. As a consequence, brushing duration varies widely due to interindividual differences in toothbrushing.

Once German adolescents have reached 18 years of age, individual prophylaxis is no longer supported by health insurance. Thereafter, no systematic assistance in oral hygiene behaviour is provided. At this time, it is assumed that a sufficient level of education in oral hygiene behaviour has been obtained. Whether this assumption is true has not yet been investigated, which makes this age group very interesting for investigations assessing the results of preventive programmes.

Despite the intensive efforts to establish good oral hygiene performance, self-performed mechanical plaque removal is often not sufficiently effective [van der Weijden and Hioe, 2005], and it is the daily experience of clinicians that patients exhibit considerable amounts of plaque although they are reportedly engaged in oral hygiene. The reason for this discouraging finding is not well understood. The performance of oral hygiene procedures has mainly been investigated using levels of plaque as a surrogate parameter [van der Weijden and Hioe, 2005;Slot et al., 2008;Muller-Bolla et al., 2011], but oral hygiene performance has rarely been verified by observational data, for instance, by videography [Rugg-Gunn et al., 1979;Macgregor et al., 1986;Honkala et al., 1986;Schlueter et al., 2013].

Amongst the few observational studies of toothbrushing behaviour [Robinson, 1946;Rugg-Gunn and Macgregor, 1978;Rugg-Gunn et al., 1979;Macgregor and Rugg-Gunn, 1979a;Macgregor and Rugg-Gunn, 1979b;Macgregor and Rugg-Gunn, 1984;Macgregor and Rugg-Gunn, 1985;Macgregor et al., 1986;Macgregor and Rugg-Gunn, 1986;Ganss et al., 2009;Schlueter et al., 2010;Sandstrom et al., 2011;Sharma et al., 2012;Graetz et al., 2013;Schlueter et al., 2013], the group of Macgregor and Rugg-

Gunn provided the most complete and systematic approach. They investigated various age groups and various parameters of toothbrushing behaviour, including movement patterns. The conclusion drawn from these studies was that the duration of brushing in various areas of the mouth varied considerably and that the oral surfaces were rarely brushed. The subjects used more than one type of brushing stroke, with a high frequency of alternations between the areas of the mouth being brushed, and there was a strong tendency to move the toothbrush from the left to the right. These findings clearly show a marked difference between the recommendations for toothbrushing, particularly brushing systematically, and what was implemented in daily practice. These studies were published more than two decades ago and have not been repeated since then.

The removal of plaque with a toothbrush should be complemented with suitable brushing aids for interproximal hygiene [Bergenholtz et al., 1984] because interproximal tooth surfaces are frequently coated with plaque and consequently have a high risk of developing caries [Kinane, 1998]. For this purpose, dental floss and interdental brushes are suitable, with the latter possibly being more effective [Slot et al., 2008]. Interproximal hygiene education is not part of group prophylaxis, but it appears as a recommendation in individual prophylaxis. The use of interproximal hygiene aids has become generally accepted over the years [Van der Weijden and Slot, 2011], but has not been investigated systematically until now.

Due to the lack of information about the oral hygiene habits of young adults, a collaborative study was conducted by the Department of Conservative and Preventive Dentistry, Dental Clinic, Justus-Liebig-University, Giessen, Germany; the Institute of Medical Psychology, Justus-Liebig-University, Giessen, Germany; and the Faculty of Psychology, Philipps-University, Marburg, Germany to obtain data to help clarify this lack of information. The present study is part of this interdisciplinary project on the psychological determinants and practical implementation of oral hygiene among subjects during the transition to adulthood.

The improvement of oral hygiene instruction strategies requires a sufficient understanding of actual oral hygiene behaviours. Therefore, the aim of the present part of the study was to collect data on essential oral hygiene parameters by observing and descriptively analysing the oral hygiene performance of young adults (18-19 years of age) with regard to brushing and flossing habits. According to the aforementioned targets of prevention and the general discussed aspects of mechanical plaque control [Muller-Bolla et al., 2011;dos Santos et al., 2011], the following parameters were analysed: brushing duration, brushing patterns (start area of brushing, reached areas, brushing sequences, brushing events and brushing movements) and the usage of dental floss (technique and reached interproximal spaces).

2 METHODS AND PARTICIPANTS

2.1 Study design

This was a descriptive, cross-sectional and non-disguised observational study involving healthy subjects living in Giessen in the state of Hesse (Germany). The data were collected during the year 2011 in the Department of Conservative and Preventive Dentistry, Dental Clinic, Justus-Liebig-University, Giessen, Germany. The investigation comprised selecting and obtaining informed consent from subjects, performing plaque index assessments according to Silness and Loe [1964], video recording habitual oral hygiene procedures and completing questionnaires. The study was conducted according to the guidelines of Good Clinical Practice and the Declaration of Helsinki, and it was approved by the local independent ethics committee (No. 94/10; Ethik-Kommission des Fachbereichs Medizin der Justus-Liebig-Universität Giessen).

2.2 Responsibilities

Three institutes were involved in the implementation of this study (fig. 1):

1. Department of Conservative and Preventive Dentistry, Dental Clinic, Justus-Liebig-University, Giessen, Germany (Dent-GI).
   Persons involved: Prof. Dr. C. Ganss (C.G.), Dr. N. Schlueter (N.S.) and T. Winterfeld (T.W.).
2. Institute of Medical Psychology, Justus-Liebig-University, Giessen, Germany (Psych-GI).
   Persons involved: Prof. Dr. R. Deinzer (R.D.), D. Harnacke (D.H.) and L. Wilhelm (L.W.).
3. Faculty of Psychology, Philipps-University, Marburg, Germany (Psych-MR).
   Persons involved: Dr. J. Margraf-Stiksrud (J.M-S.) and J. Illig (J.I.).

All conversations, telephone dialogues, welcome/information/inclusion procedures, introduction to video observation and completion of questionnaires were standardised, as were the clinical and technical procedures. Before the beginning of the study, all of the investigators were trained and calibrated in detail regarding their individual procedures.

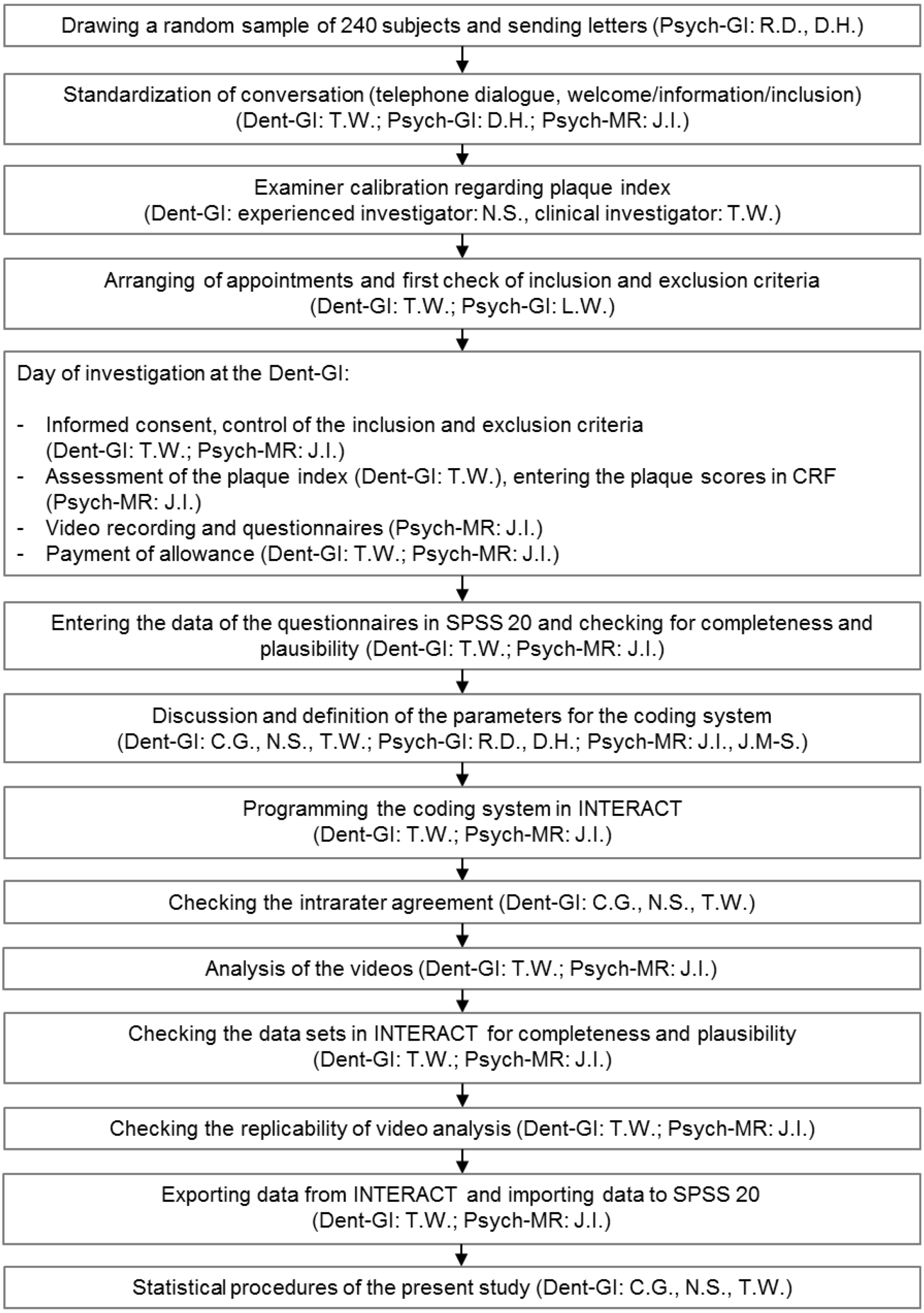


Figure 1: Flowchart of the study procedures and responsibilities regarding the present part of the project. **Dent-GI** = Department of Conservative and Preventive Dentistry, Dental Clinic, Justus-Liebig-University, Giessen, Germany; Prof. Dr. C. Ganss (**C.G.**), Dr. N. Schlueter (**N.S.**), T. Winterfeld (**T.W.**). **Psych-GI** = Institute of Medical Psychology, Justus-Liebig-University, Giessen, Germany; Prof. Dr. R. Deinzer (**R.D.**), D. Harnacke (**D.H.**), L. Wilhelm (**L.W.**). **Psych-MR** = Faculty of Psychology, Philipps-University, Marburg, Germany; Dr. J. Margraf-Stiksrud (**J.M-S.**), J. Illig (**J.I.**). **CRF** = case report form; **INTERACT** = Video observation and coding software; **SPSS 20** = Statistical software.

2.3 Recruitment of subjects and inclusion

The recruitment of subjects was based on a register of the residents of Giessen. By means of this register, a random sample of 240 subjects was drawn. These individuals were informed via cover letters sent successional in five groups: four groups contained 50 subjects each, and one group contained 40 subjects. The volunteers had the opportunity to respond by e-mail or telephone; if the subject replied by e-mail the appointment was also scheduled by telephone using a standardised protocol (appendix 8.1).

The inclusion criteria were as follows: willing and able to provide informed consent, male or female, born in 1992, not involved in dentistry (dental nurses or dental students), no fixed orthodontic appliances, no removal dentures, no mental or physical disability with the potential to influence oral hygiene and no routine use of a powered toothbrush.

The inclusion criteria were requested during the telephone call; therefore, only suitable subjects received appointments. Among the responders to the first letter, 71 participants received appointments. Individuals who did not reply to the first letter (n = 153) were telephoned if their number was found in the public telephone directory (n = 41), resulting in 14 additional appointments. All the remaining subjects were approached a second time (n = 112), resulting in 16 scheduled appointments. The response rate was 42%. Personal data were pseudonymised using four-digit numbers. A total of 101 subjects were included.

2.4 Information and consent

Each participant received written information about the study on the day of the examination. The inclusion and exclusion criteria were confirmed. The four-digit number of each participant was registered on the questionnaires, case report file and informed consent form. The case report file and the informed consent were stored separately from each other for the pseudonymisation of the participant.

2.5 Implementation of the study

2.5.1 Assessment of plaque index

To evaluate the participants' oral hygiene conditions, the plaque index (PI) according to Silness and Loe [1964] was recorded before the toothbrushing performance was videotaped. The PI assessment was performed visually by T.W. after the isolation of the teeth using cotton rolls and with the help of a periodontal probe (Aesculap DB768R, PCP11, Tuttlingen, Germany). All the teeth were included, with the exception of wisdom teeth and unassessable teeth (i.e., teeth with at least one surface that had been destroyed by caries). The PI scores (tab. 1) for the vestibular and oral tooth surfaces were recorded and entered into a CRF by J.I. (fig. 3, chapter 2.5.5). To minimise bias, the participants were not informed about their oral hygiene status until all the study procedures were completed.

Table 1 Grading of the Plaque Index System by Silness and Loe [1964].

Scores	Criteria
0	No plaque.
1	A film of plaque adhering to the free gingival margin and adjacent areas of the tooth. The plaque may be observed using the probe on the tooth surface.
2	Moderate accumulation of plaque on the tooth and gingival margin, which is visible to the naked eye.
3	Abundance of plaque on the tooth and gingival margin, often covering the tooth surface.

2.5.2 Video recording

After the plaque scores were recorded, the participant was led to an extra prepared room (a simulation of a washbasin bathroom), where brushing could be performed without any disturbances. An image of the breadboard construction is shown in figure 2.

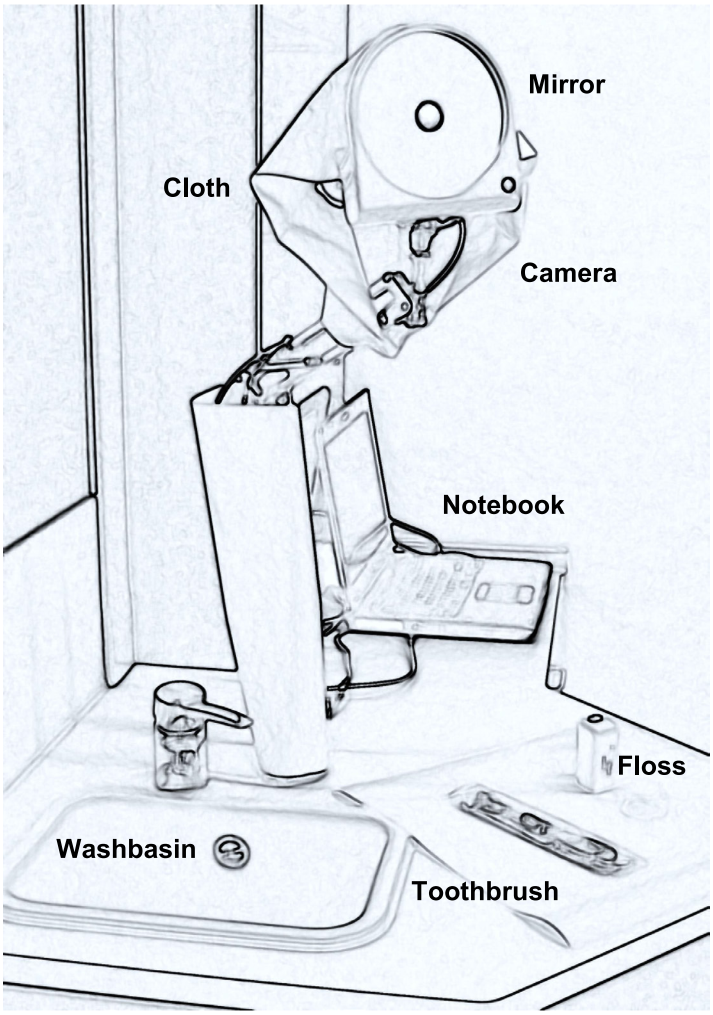


Figure 2: Breadboard construction: a camera is connected to a notebook computer and covered by a cloth behind a parabolic mirror; a toothbrush and floss are provided.

2.5.2.1 Description of equipment

- Video camera (JVC, GR-D230E, Friedberg, Hesse, Germany)
- Parabolic mirror (total diameter = 135 mm; diameter of the hole for the objective lens = 24 mm)
- Notebook computer for video recording: Acer TravelMate 5720-602G16 (Core 2 Duo T7500, graphic controller Intel GMA X3100, firewire connection)
- Software: Windows XP, Windows Movie Maker; Video format: .avi (DVCPRO), 25 frames per second (fps)
- Toothbrush: elmex® inter X, GABA, Lörrach, Germany; brushing head: short, bristle stiffness: medium
- Floss: Johnson & Johnson Reach Waxed Dentotape, New Brunswick, New Jersey, USA; length: approx. 0.5 m

2.5.2.2 Preliminaries

The clinical examiner (T.W.) obtained informed consent and confirmed the inclusion and exclusion criteria while the second examiner (J.I.) prepared the oral hygiene room; the area was disinfected, and a toothbrush and floss were provided. Windows Movie Maker was started, and the code number of the participant was used for the designation of the video file.

2.5.2.3 Obtaining video recordings of toothbrushing

The recording was performed by one investigator (J.I.) using a video camera installed behind a parabolic mirror on a tripod (fig. 2). The hole in the middle of the mirror had the same diameter as the objective lens. The participant was invited, according to a standardised conversation protocol, to clean her/his teeth in the usual way. For this purpose, a standardised toothbrush and floss were provided. No toothpaste was used to simplify the analysis of the video. The participant was positioned in front of the parabolic mirror so that she/he was standing in the focus of both the mirror and the camera. The participant brushed with no other individuals present during the video recording but knew that she/he was being filmed. The recording was saved directly on a connected notebook computer. After the toothbrushing performance was finished, the participant left the room and informed the investigator that she/he had stopped brushing. The purpose of this step was to prevent the participant from being interrupted prematurely.

2.5.3 Data collection with questionnaires

Immediately following the videotaping of the oral hygiene performance, the questionnaires were completed (oral hygiene habits according to DMS IV, periodontitis-relevant knowledge, SWEB, OHIP-G14, DAS, and graduation).

The data concerning the participants' oral hygiene habits and demographics (gender and parents' education level; appendix 8.2) were relevant to the present study. All the remaining questionnaires were in the interest of the psychological part of the study (Psych-GI and Psych-MR) and are not represented in the present part.

The participants answered the questionnaires without being disturbed. After completing the questionnaires, each participant placed them in an envelope and gave it to one of the investigators. The questionnaires were analysed after the video observation phase of the study was completed.

2.5.3.1 Education level

The education level of each participant was determined by the highest level of education attained by the parents. Classification into *low level of formal education*, *middle level of formal education* and *high level of formal education* was determined by the categorisation of the parents' level of formal education according to the Deutsche Mundgesundheitsstudie III (DMS III) [Micheelis and Schroeder, 1999] (tab. 2). For participants who provided information about both their mother's and father's education, the higher education level was selected.

Table 2 Categories of parents' formal education according to the Deutsche Mundgesundheitsstudie III [Micheelis and Schroeder, 1999].

Category of parents' formal education	**Types of school-leaving qualifications**
Low level of formal education	Certificate of Secondary Education or no graduation
Middle level of formal education	O-level or other graduation
High level of formal education	Advanced technical college certificate or Abitur or certificate of completed studies

2.5.3.2 Classification of the oral hygiene level

The level of the participants’ oral hygiene was classified as good or bad according to the Deutsche Mundgesundheitsstudie IV (DMS IV) [Micheelis, 2006b].

Good oral hygiene level

Three criteria had to be fulfilled for a good oral hygiene level: a participant brushed (I) at least twice per day and (II) at least twice per day ‘after a meal’ or ‘before going to bed’ and (III) with a brushing duration of at least 2 minutes.

Bad oral hygiene level

All the participants who did not fulfil the aforementioned criteria according to their own statements were classified as having a bad oral hygiene level.

2.5.4 Quality assurance

This study was conducted according to the guidelines of Good Clinical Practice and the Declaration of Helsinki. All responsibilities were fulfilled in accordance with the protocol, and all the participants received detailed information about all the procedures. The examiners (J.I. and T.W.) were trained and calibrated with regards to the standardised processes. The collected data (case report forms [CRFs], videos and questionnaires) were pseudonymised and were archived separately from the personal data (informed consent). All the handwritten data from the CRFs and the questionnaires were transferred to an SPSS file (J.I. and T.W.). Subsequently, this file was checked for correctness and plausibility (J.I. and T.W.), and the data sets in INTERACT were checked for plausibility and completeness (J.I. and T.W.). The final SPSS file of the video analysis was checked again for plausibility.

2.5.5 Video analysis

The video recordings were analysed after the completion of the data collection. Each video was analysed by both investigators (J.I. and T.W.) independently of one another at two different institutes (Dent-GI and Psych-MR) over a period of 4 months.

For the analysis, the upper and lower jaws were divided into sextants (fig. 3): sextant 1 = teeth 17 to 14; sextant 2 = teeth 13 to 23; sextant 3 = teeth 24 to 27; sextant 4 = teeth 37 to 34; sextant 5 = teeth 33 to 43; and sextant 6 = teeth 44 to 47. Hereafter, the abbreviations S1–S6 are used to indicate sextant 1–sextant 6, respectively. Furthermore, each sextant was divided into three different tooth surfaces (vestibular, occlusal and oral). Each combination of a sextant and a tooth surface was defined as an area.

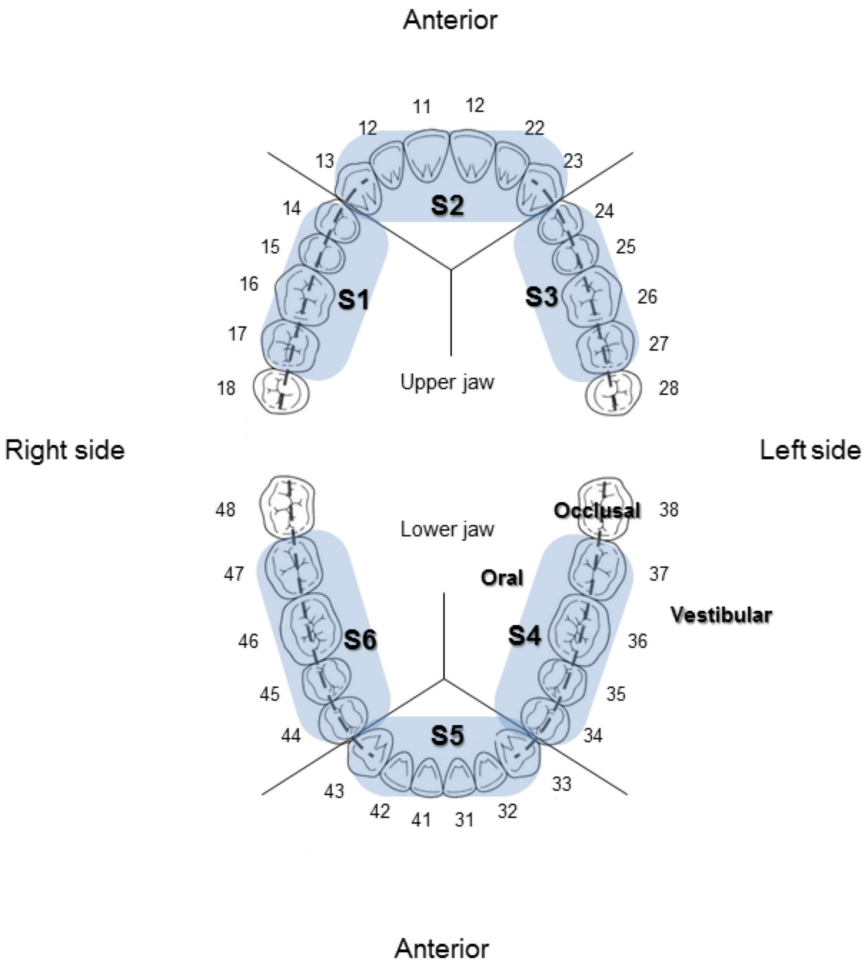


Figure 3: Division of the upper and lower jaws into sextants; outside number = Fédération Dentaire Internationale (FDI) numbering scheme (teeth 18 to 48); blue = sextant 1–sextant 6 (S1–S6); the third molars (white) were not considered. The tooth surfaces were divided into oral, occlusal and vestibular. Modified by T.W.; original by Rateitschak et al. [2004].

2.5.5.1 Parameters of toothbrushing

Different basic parameters of toothbrushing were assessed (tab. 3). The video analysis and the composition of these parameters are explained in detail in chapter 2.5.5.3. The combination of these parameters allowed an extended and differential subsequent analysis.

Table 3 Parameters of toothbrushing [Winterfeld et al., 2015] (with permission of Springer Science+Business Media)

Parameter	Description
Handedness	The hand holding the toothbrush (left, right or both).
Total brushing duration	The time between the first and last moments of contact between the toothbrush and the teeth.
Effective brushing duration [Honkala, 1984]	The time during which the toothbrush was retained in the mouth = total brushing duration without interruptions such as rinsing, spitting or breaks.
Brushing strokes	Circular, horizontal-linear, vertical-linear, vertical-roll, jiggling (short horizontal) and unspecific brushing movements.
Starting location	The first area (oral, vestibular, or occlusal and right side, left side or anterior) reached at the beginning of toothbrushing.
Brushing events [Macgregor and Rugg-Gunn, 1979a]	The frequency of alternations between the sextants, the tooth surfaces (oral, vestibular and occlusal) or a combination of both (area).

2.5.5.2 Parameters of flossing

The analysis of flossing performance included the following parameters: whether floss was used, the sextants reached during flossing, flossing frequency and flossing technique (tab. 4). For the posterior teeth in sextants 1, 3, 4 and 6, three interproximal spaces are accessible (between the first and second premolars, between the second premolar and the first molar and between the first and second molars). For example, in sextant 1, accessible interproximal spaces exist between teeth 17 and 16; 16 and 15; and 15 and 14. For the anterior teeth in sextant 2 and sextant 5, seven interproximal spaces are accessible (posterior from one canine tooth to the opposite canine tooth in each jaw).

The flossing data of five participants (out of 47) were evaluable only with respect to whether they flossed. Further analyses of the reached sextants and flossing technique were not possible.

Table 4 Parameters of flossing [Winterfeld et al., 2015] (with permission of Springer Science+Business Media)

Parameter	Description
Floss was used	Yes / No
Reached sextant	Complete: each interproximal space in a sextant was approached at least once. Incomplete: at least one but not all of the interproximal space/s in a sextant was/were approached. Not reached: no interproximal space in a sextant was approached.
Flossing frequency	The sum of the reached interproximal spaces per sextant. Every event and the repeated flossing of the same interproximal space were recorded.
Flossing technique	Horizontal movements; brief insertion into and removal from the interproximal space directly ("in and out"); vertical movements; draw through.

2.5.5.3 Video coding system and definition of the variables

The professional video coding and analysis software INTERACT 9 [Mangold, 2011] was used to analyse the videos. We developed a novel observation method with a corresponding coding system in INTERACT. Videos were controlled directly in this program (fig. 4). Every observed variable was assigned a code (figs. 5-8), and each code was assigned a shortcut key (hotkey). During the video analysis, each observed variable was logged into a data set by pressing the corresponding hotkey. Single timed events, the duration of events and multiple simultaneous events could be coded. The analysis was performed with up to four passes of coding; thus, every video had to be watched up to four times (figs. 5-8). A description of the columns in figures 5-8 (below) according to the INTERACT manual is provided in table 5.

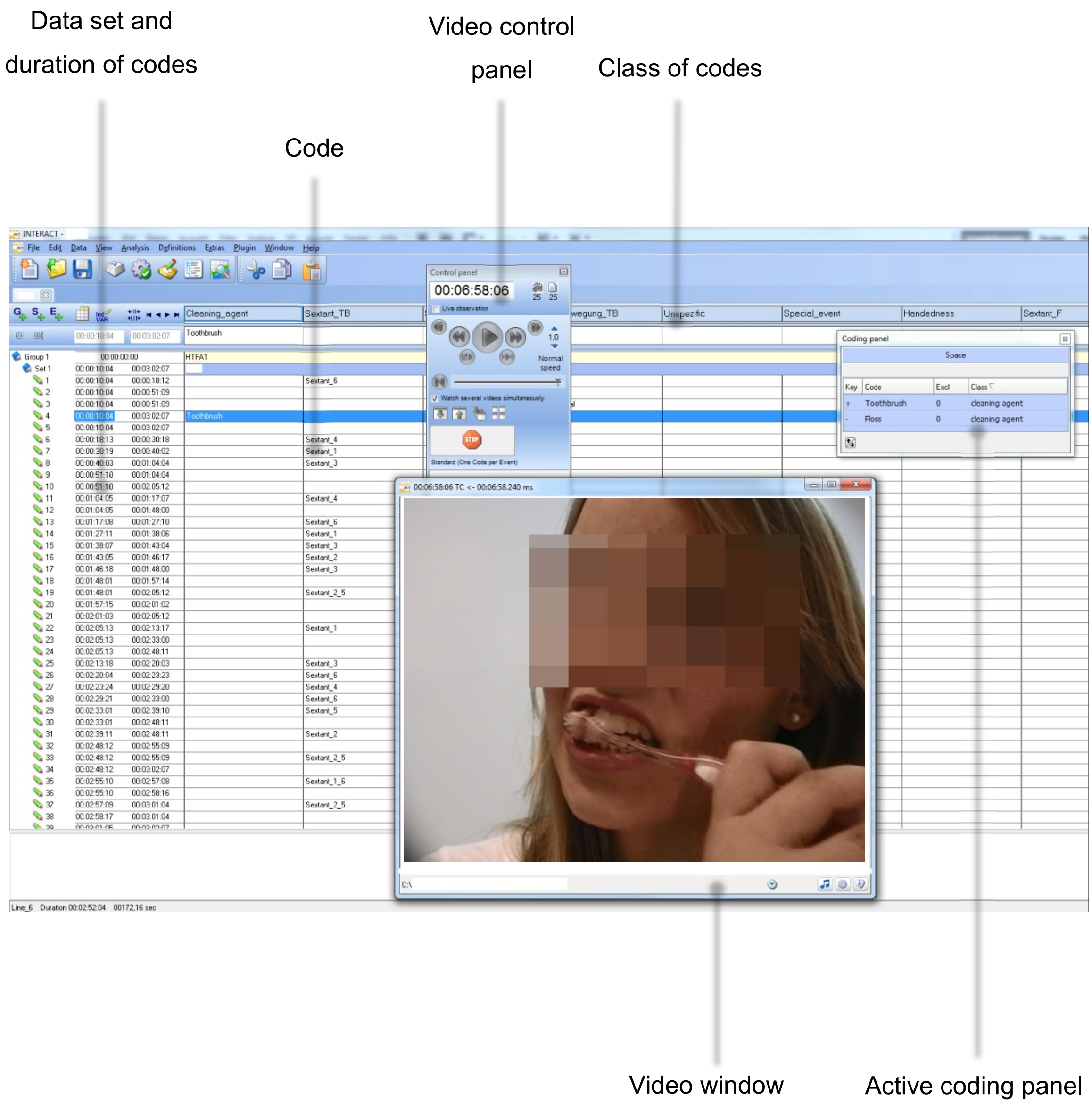


Figure 4: Screenshot of the user interface of INTERACT 9 [Mangold, 2011].

Table 5 Description of the columns in figures 5-8 (below).

Column	**Description**
Key	Shortcut keys assigned to each code
Code	Descriptive phrase for the variable being observed
Dur	Checked marker: to log codes with a duration, un-checked marker: to log codes with a single point in time
Excl	Codes with the same number exclude each other
Class	Superior class of several codes
Lex.chain	Not used
Prefix and EOC	Not used

In the **first pass** of the analysis, the brushing duration and the usage of dental floss were coded (fig. 5).

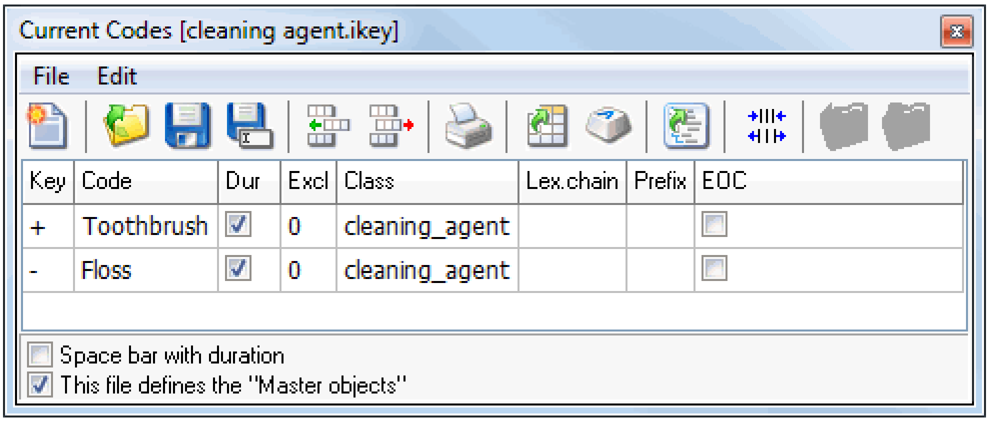


Figure 5: Screenshot of the first pass of coding; capture of brushing duration (Toothbrush) and whether dental floss was used (Floss).

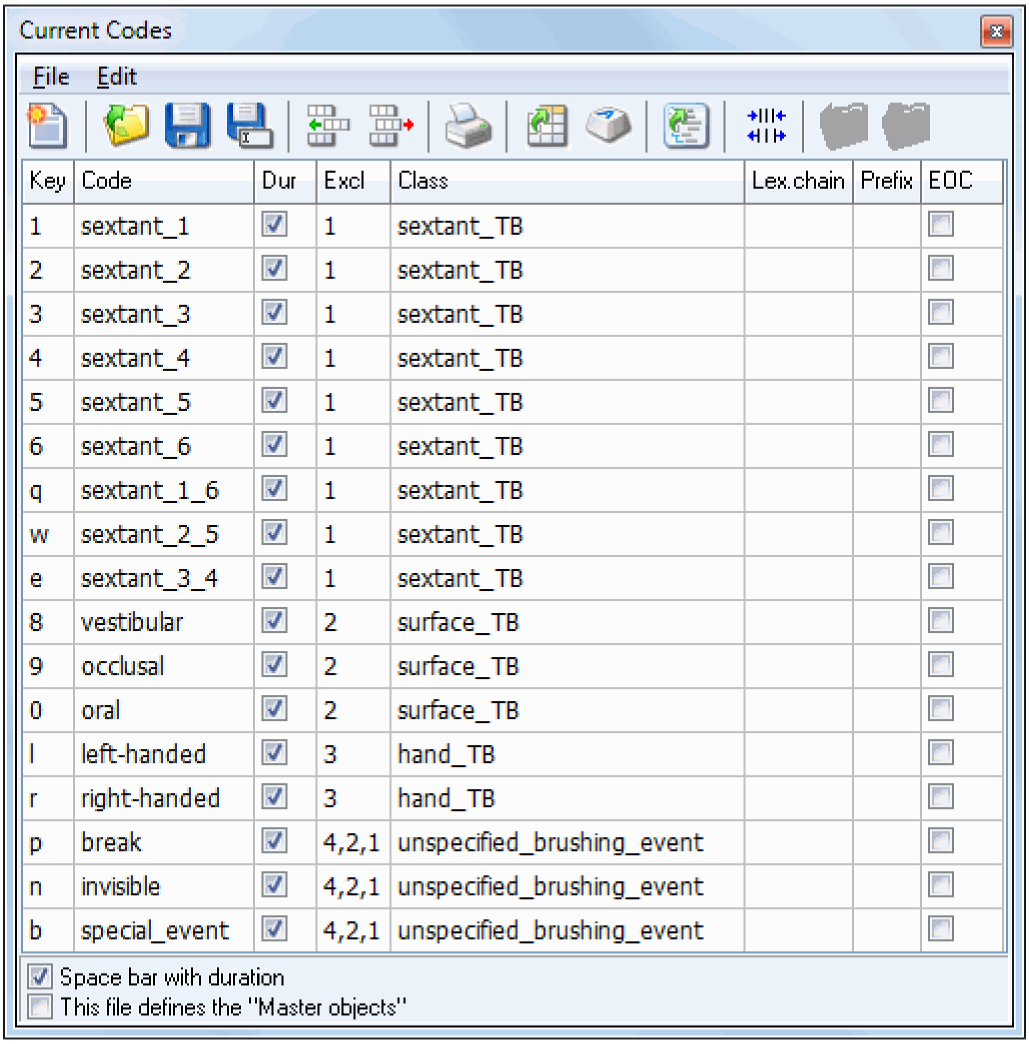
Toothbrush

The brushing duration was captured by the code *Toothbrush* as soon as the toothbrush was placed on the tooth surface. The event was terminated after the last contact between the toothbrush and the teeth. To determine the overall duration of the brushing process, the brushing duration was not stopped if it was interrupted by events such as rinsing, spitting or breaks.

Floss

The code *Floss* was started as soon as the participant flossed the first interproximal space, and it was stopped after the last interproximal space was flossed. During an interim break, the event was not stopped.

In the **second pass** of the analysis (fig. 6), the sextants reached by the toothbrush (fig. 6a), the tooth surfaces (fig. 6b), the handedness of brushing (fig. 6c) and unspecified events (breaks, invisible sections, and special events) were coded.



Key	Code	Dur	Excl	Class	Lex.chain	Prefix	EOC
1	sextant_1	☑	1	sextant_TB			☐
2	sextant_2	☑	1	sextant_TB			☐
3	sextant_3	☑	1	sextant_TB			☐
4	sextant_4	☑	1	sextant_TB			☐
5	sextant_5	☑	1	sextant_TB			☐
6	sextant_6	☑	1	sextant_TB			☐
q	sextant_1_6	☑	1	sextant_TB			☐
w	sextant_2_5	☑	1	sextant_TB			☐
e	sextant_3_4	☑	1	sextant_TB			☐
8	vestibular	☑	2	surface_TB			☐
9	occlusal	☑	2	surface_TB			☐
0	oral	☑	2	surface_TB			☐
l	left-handed	☑	3	hand_TB			☐
r	right-handed	☑	3	hand_TB			☐
p	break	☑	4,2,1	unspecified_brushing_event			☐
n	invisible	☑	4,2,1	unspecified_brushing_event			☐
b	special_event	☑	4,2,1	unspecified_brushing_event			☐

☑ Space bar with duration
☐ This file defines the "Master objects"

Figure 6: Screenshot of the second pass of coding; capture of sextants (sextant 1–sextant 6, sextant 1_6, sextant 2_5 and sextant 3_4), tooth surfaces (vestibular, occlusal and oral), handedness (left or right) and unspecified brushing events. The shortcut TB = toothbrush.

Sextant_TB

This class contained the codes *sextant 1* to *sextant 3_4*, which referred to the sextants reached with the toothbrush (TB) (fig. 6a). A sextant was considered to be reached when the head of the toothbrush reached it completely and a brushing stroke was recognised for at least one second. The event was stopped when a new sextant was reached by all of the toothbrush's bristles or when the toothbrush was removed.

If brushing strokes were performed in two sextants simultaneously, the first coded sextant remained active until the toothbrush completely reached a new sextant. Brushing strokes that were performed in the upper and lower jaws simultaneously with the jaws closed (vestibular areas of sextants 1 and 6, 2 and 5 or 3 and 4), were defined by the following extra codes: sextant 1_6, sextant 2_5 and sextant 3_4. If another sextant was touched during the alternation between sextants without an obvious brushing action or for less than one second, it was not coded; the corresponding active sextant was retained.

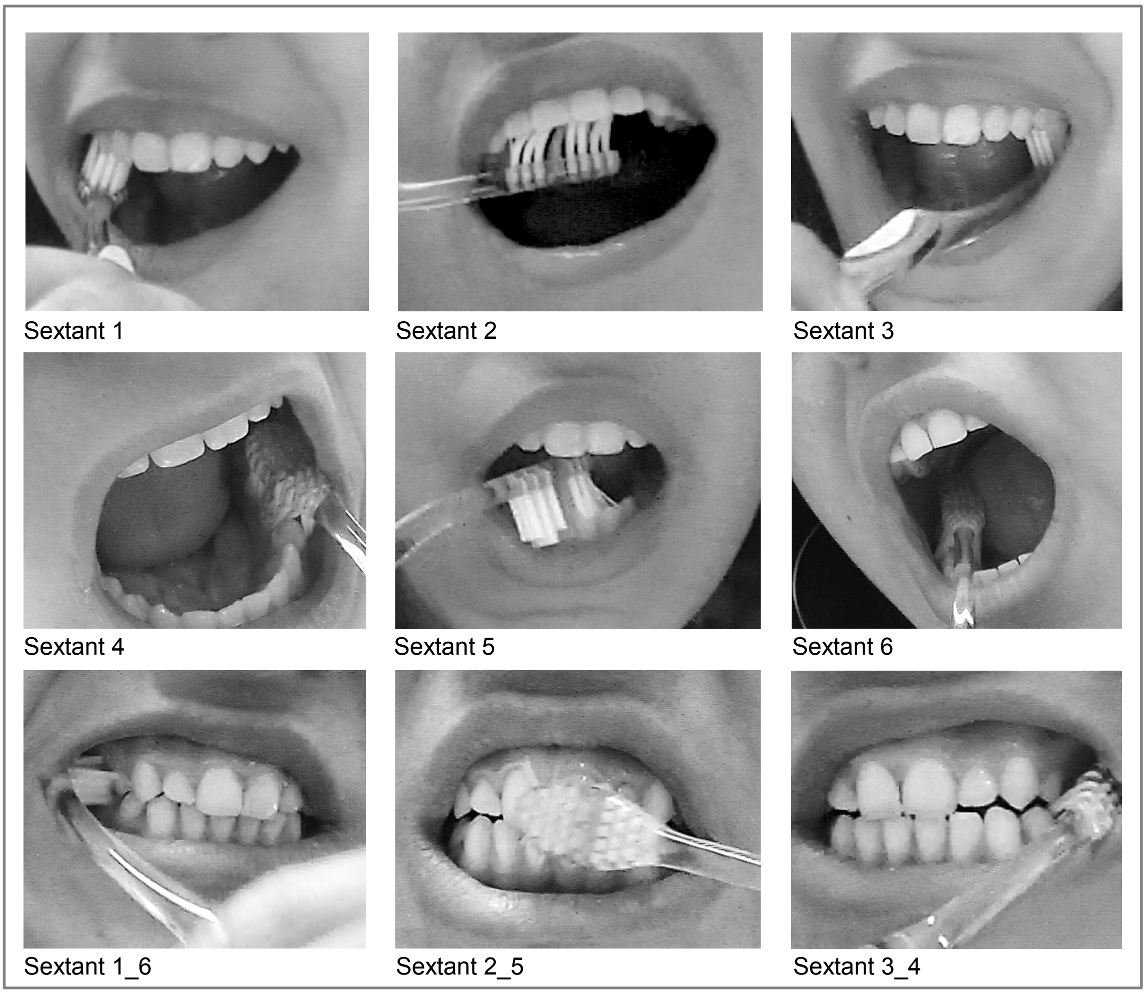


Figure 6a: The sextants (sextants 1 to sextant 3_4) reached by the toothbrush. Screenshots created from original videos.

Surface_TB

This class describes the three tooth surfaces (*occlusal*, *oral* and *vestibular*) that were reached with the toothbrush (TB) (fig. 6b). An event was coded when the total of the toothbrush's bristles had reached the area and a brushing stroke lasting at least one second was observed. The code was stopped when another tooth surface was brushed or the toothbrush was removed. If two areas were brushed simultaneously as the result of an oblique angle of attack, then the tooth surface in contact with the largest proportion of the toothbrush's bristles was coded.

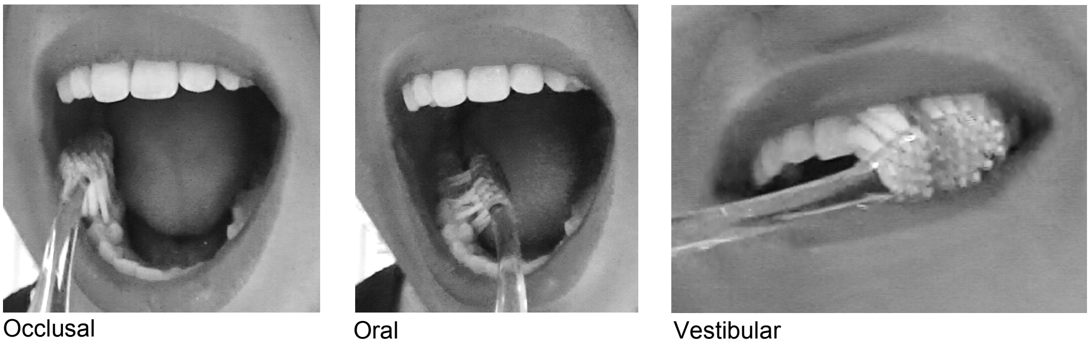


Figure 6b: The tooth surfaces (occlusal, oral and vestibular) reached by the toothbrush. Screenshots created from original videos.

Hand_TB

This class describes the hand that held the toothbrush (fig. 6c). The event was coded as soon as the brushing process started and was stopped after the last brushing stroke was performed. The event was not stopped during the entire brushing process.

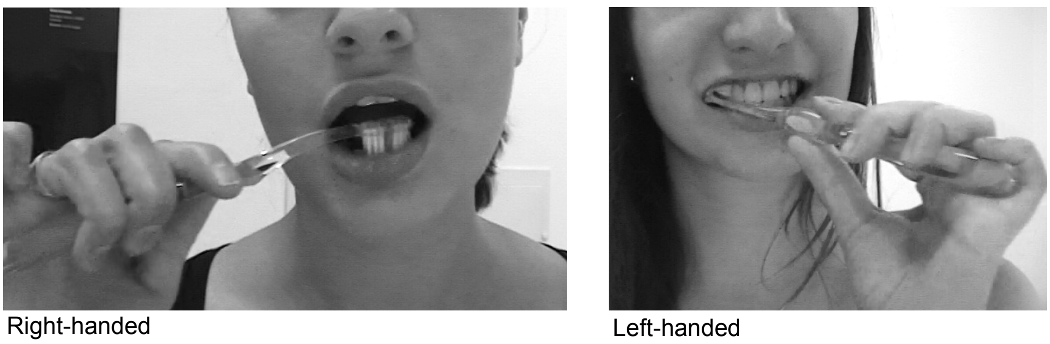


Figure 6c: Handedness of participants (left or right). Screenshots created from original

Unspecified_brushing_event

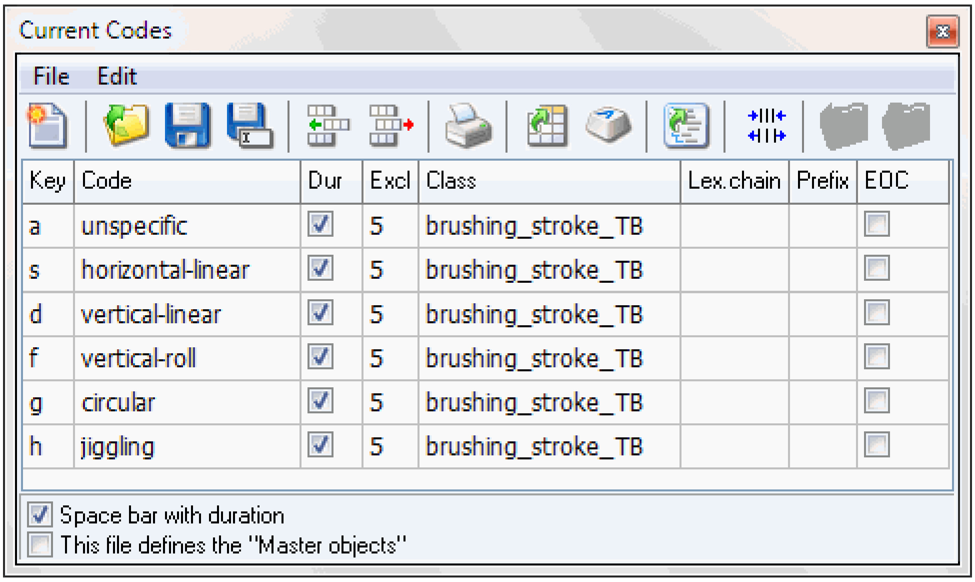
This class included the variables *break*, *invisible* and *special event*. If one of these variables was coded, all the other events were stopped, except for the variables *toothbrush*, *floss* and *hand_TB*.

The event *break* was coded when the toothbrush was removed from the mouth for, e.g., cleaning the toothbrush, rinsing or spitting. Then, brushing was continued.

The event *invisible* was coded if the exact position of the toothbrush and/or the brushing stroke could not be clearly observed (e.g., the participant was out of focus, the mouth was closed, or the position of the toothbrush could not be clearly observed).

The variable *special event* was a free-text variable designed for the registration of unforeseeable actions, such as tongue cleansing, palate cleansing or mobile phone conversations.

In the **third pass** of the analysis, the brushing strokes were coded (fig. 7). This class characterised the types of brushing movements (fig. 7a-e) performed with the toothbrush (TB). If one of these variables was coded, the previous variable was stopped.



Key	Code	Dur	Excl	Class	Lex.chain	Prefix	EOC
a	unspecific	☑	5	brushing_stroke_TB			☐
s	horizontal-linear	☑	5	brushing_stroke_TB			☐
d	vertical-linear	☑	5	brushing_stroke_TB			☐
f	vertical-roll	☑	5	brushing_stroke_TB			☐
g	circular	☑	5	brushing_stroke_TB			☐
h	jiggling	☑	5	brushing_stroke_TB			☐

Figure 7: Screenshot of the third pass of coding; capture of brushing strokes (unspecific, horizontal-linear, vertical-linear, vertical-roll, circular, and jiggling). The shortcut TB = toothbrush.

Horizontal-linear

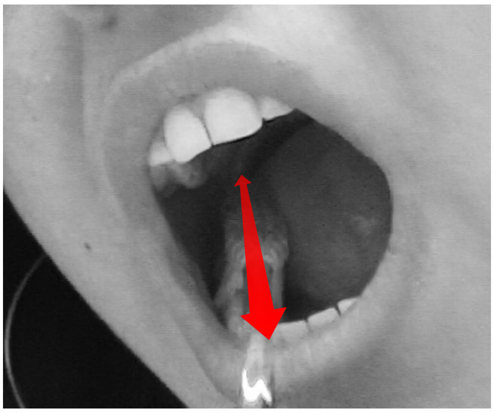


Figure 7a: Horizontal-linear: anterior and posterior movements of the toothbrush head and bristle ends in a horizontal direction, parallel to the occlusal plane. This brushing stroke was codeable on all surfaces (occlusal, oral and vestibular). Screenshot created from original video.

Vertical-linear

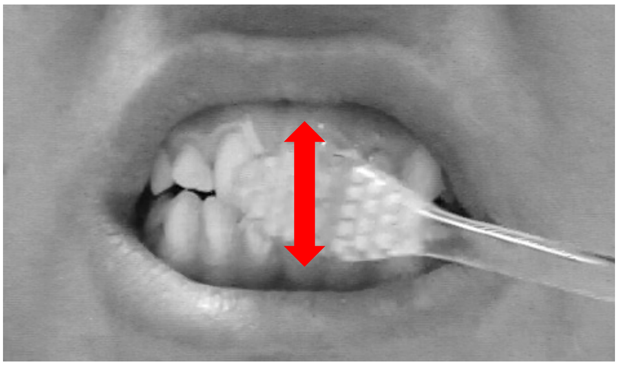


Figure 7b: Vertical-linear: Brushing movements in a cervical to coronal ('red to white') direction or vice versa, parallel to the tooth axis. This brushing stroke was codeable on the vestibular and oral tooth surfaces (occlusal was impossible by definition). Screenshot created from original video.

Vertical-roll

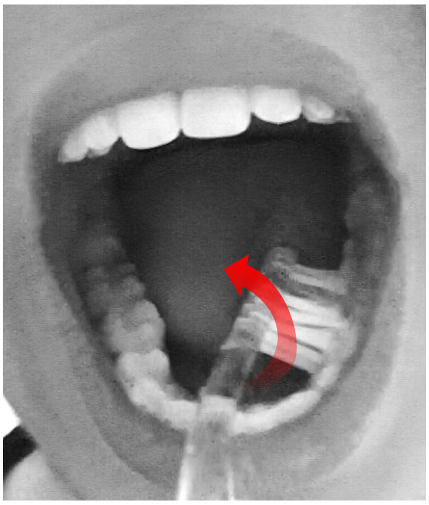


Figure 7c: Vertical-roll: vertical movement in a cervical to coronal direction with the additional rotary movement of the toothbrush on its own axes. This brushing stroke was codeable on the vestibular and oral tooth surfaces (occlusal was impossible by definition). Screenshot created from original video.

Circular

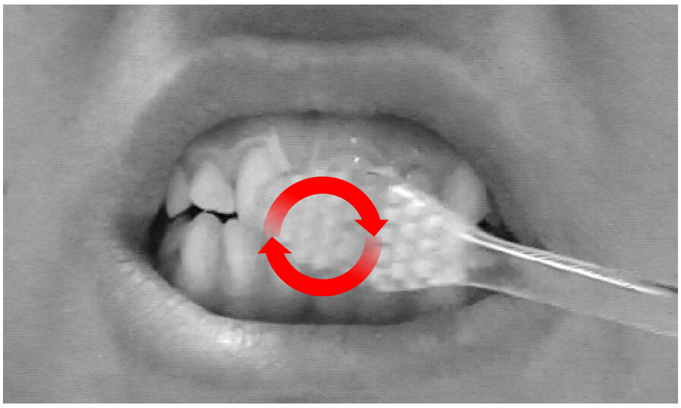


Figure 7d: Circular: a circular movement of the toothbrush's head and bristle ends in one sextant or a combination of sextants. This brushing stroke was codeable on all tooth surfaces (occlusal, oral and vestibular). Screenshot created from original video.

Jiggling

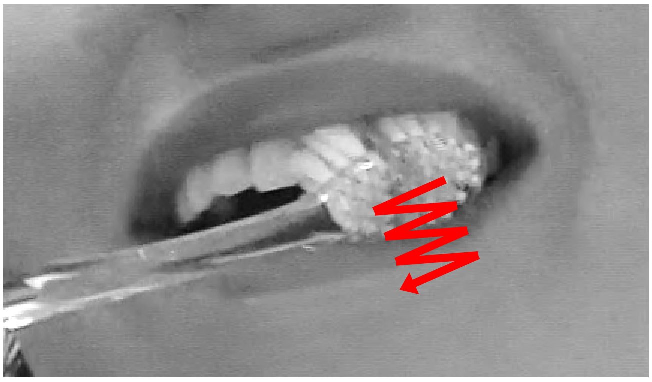
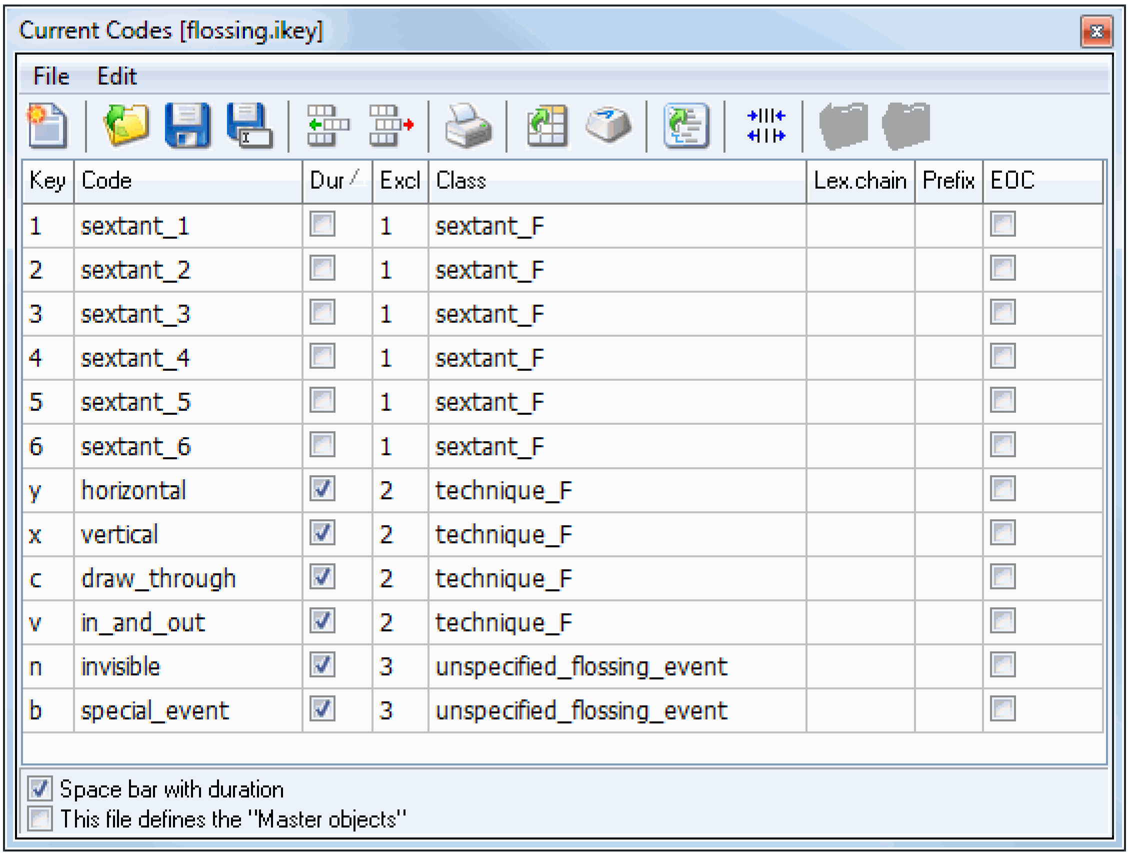


Figure 7e: Jiggling: a short, horizontal movement of the toothbrush's head and bristle ends during which the bristles remained in place. Screenshot created from original video.

Every brushing stroke that could not be assigned to one of the abovementioned variables was coded as *unspecific* brushing stroke.

A **fourth pass** of the analysis was necessary if the participant had flossed (fig. 8).



Current Codes [flossing.ikey]

File Edit

Key	Code	Dur	Excl	Class	Lex.chain	Prefix	EOC
1	sextant_1	☐	1	sextant_F			☐
2	sextant_2	☐	1	sextant_F			☐
3	sextant_3	☐	1	sextant_F			☐
4	sextant_4	☐	1	sextant_F			☐
5	sextant_5	☐	1	sextant_F			☐
6	sextant_6	☐	1	sextant_F			☐
y	horizontal	☑	2	technique_F			☐
x	vertical	☑	2	technique_F			☐
c	draw_through	☑	2	technique_F			☐
v	in_and_out	☑	2	technique_F			☐
n	invisible	☑	3	unspecified_flossing_event			☐
b	special_event	☑	3	unspecified_flossing_event			☐

☑ Space bar with duration
☐ This file defines the "Master objects"

Figure 8: Screenshot of the fourth pass of coding; coding of the sextants reached by the floss (sextant 1 to sextant 6), the flossing technique (horizontal, vertical, draw_through, or in_and_out) and unspecified flossing events (invisible or special event). The shortcut F = floss.

Sextant_F

This class included the sextants reached by the floss (F) (fig. 8a). One event was coded for each flossed interproximal space in the respective sextant. This event was a single event without duration. One interproximal space could be coded multiple times. The total number of coded events did not allow a clear determination of whether a sextant was reached completely by the floss. This was coded in the variable *special event*, a free-text variable that was used only if a participant flossed a sextant incompletely (e.g., sextant 2 was flossed 18 times by one participant, but only two different interproximal spaces were reached). If a participant flossed every interproximal space of a sextant, the variable *special event* was not coded; the number of events indicated the completeness. If a participant flossed two interproximal spaces simultaneously, both of the appropriate sextants were coded.

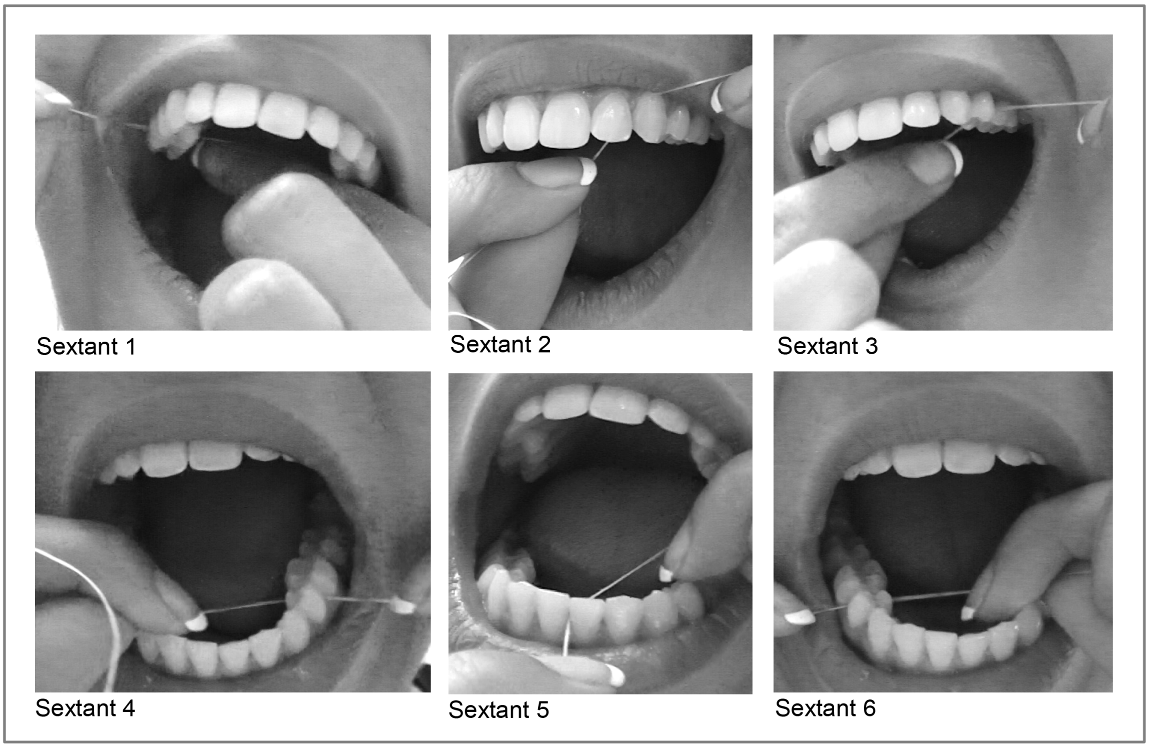


Figure 8a: The sextants (sextant 1 to sextant 6) reached by the floss. Screenshots created from original videos.

Technique_F

The flossing (F) technique class described the movements performed with the dental floss. If one of these variables was coded, the previous variable was stopped (fig. 8b-e).

Horizontal

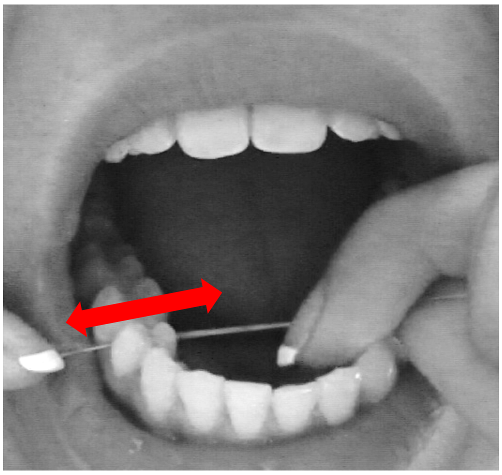


Figure 8b: Horizontal: After the floss was threaded into the interproximal space, horizontal movements parallel to the occlusal plane were performed. Screenshot created from original video.

Vertical

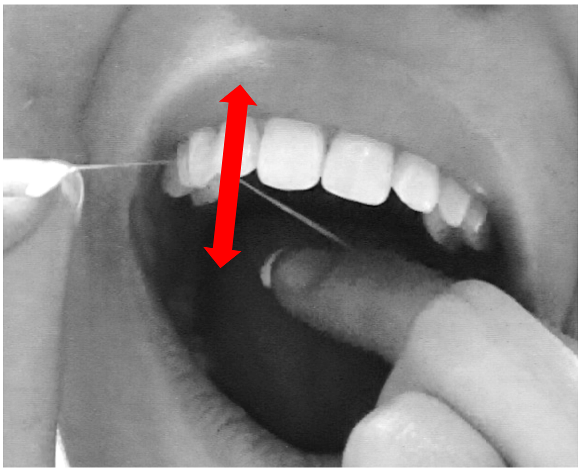


Figure 8c: Vertical: After the floss was threaded into the interproximal space, up-and-down movements parallel to the tooth axis on the proximal tooth surfaces were performed at least twice. Screenshot created from original video.

Draw_through

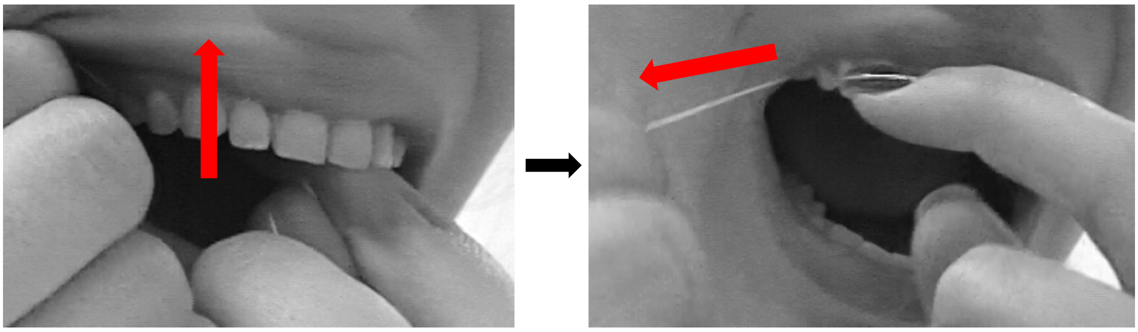


Figure 8d: Draw_through: After the floss was threaded into the interproximal space, it was directly pulled out vertically to the tooth axis in the oral or vestibular direction without any other movements. Screenshots created from original videos.

In_and_out

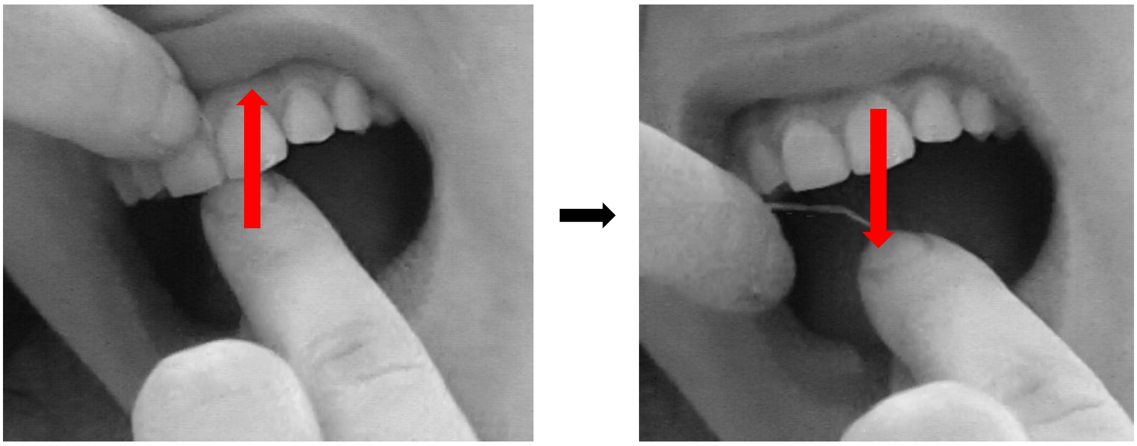


Figure 8e: In_and_out: After the floss was threaded into the interproximal space, it was removed directly without any other movements, as described above. Screenshots created from original videos.

Unspecified_flossing_event

Previously, the events in this class could not be standardised. This category included the variables *invisible* and *special event*. The variable *invisible* was coded if the position of the dental floss was not clearly visible, e.g., if the lips were closed. The variable *special event* has already been described above.

2.5.5.4 Parameters of movement patterns

In addition to the statistical data, the coded events could be visualised chronologically in INTERACT using a timeline chart (figs. 9a, b–11a, b). An individual timeline chart containing the observed parameters was created for every participant. This chart showed the total duration of the toothbrushing process and the duration of every coded event in chronological order depicted as single or multiple bars in different colours. Based on these graphics, three different categories of movement patterns were defined (tab. 6).

Table 6 Parameters of movement patterns

Parameter	Description
Systematic (fig. 9a, b)	Brushing performed in the following order: - A previously established sequence (analogous to the system of Rateitschak [Rateitschak et al., 2004]. - First the upper, then the lower jaw, or vice versa. - First the oral, then the vestibular tooth surfaces, or vice versa.
Sequential (fig. 10a, b)	A brushing sequence consisting of at least four batched brushing events. This sequence had to be repeated at least three times. The variable of interest was the alternation between sextants.
Unstructured (fig. 11a, b)	No systematic or sequential movement pattern was recognisable.

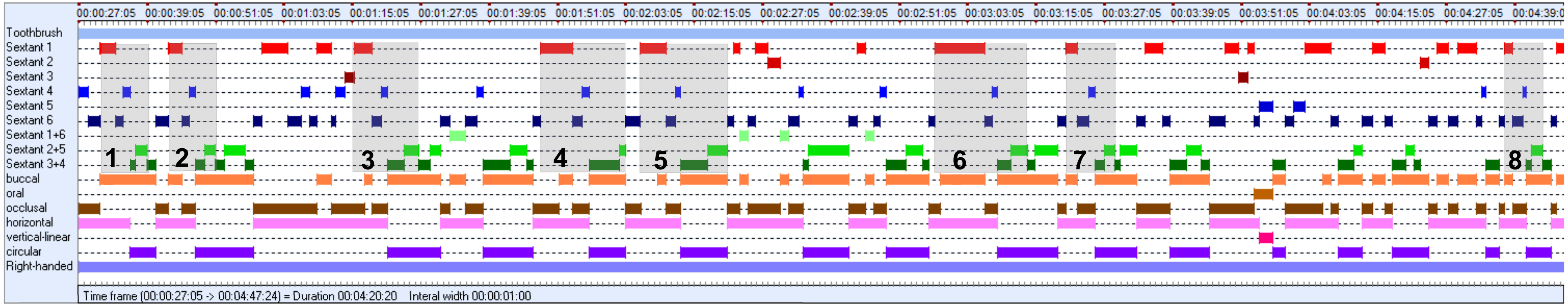


Figure 9a: Sequential brushing pattern.

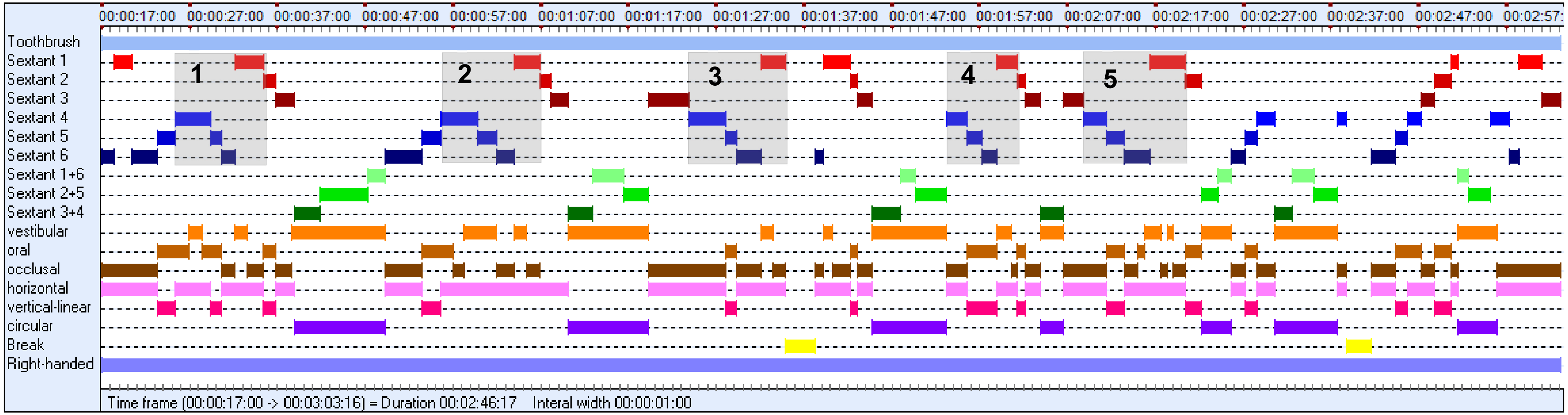


Figure 9b: Sequential brushing pattern.

The events that composed a sequence are highlighted by the grey boxes. The sequence in figure 9a included the following events: s*extant 1 – sextant 6 – sextant 4 – sextants 3_4 – sextants 2_5*, which were repeated eight times (numbers 1–8). The sequence in figure 9b included the following events: s*extant 4 – sextant 5 – sextant 6 – sextant 1,* which were repeated five times (numbers 1–5).

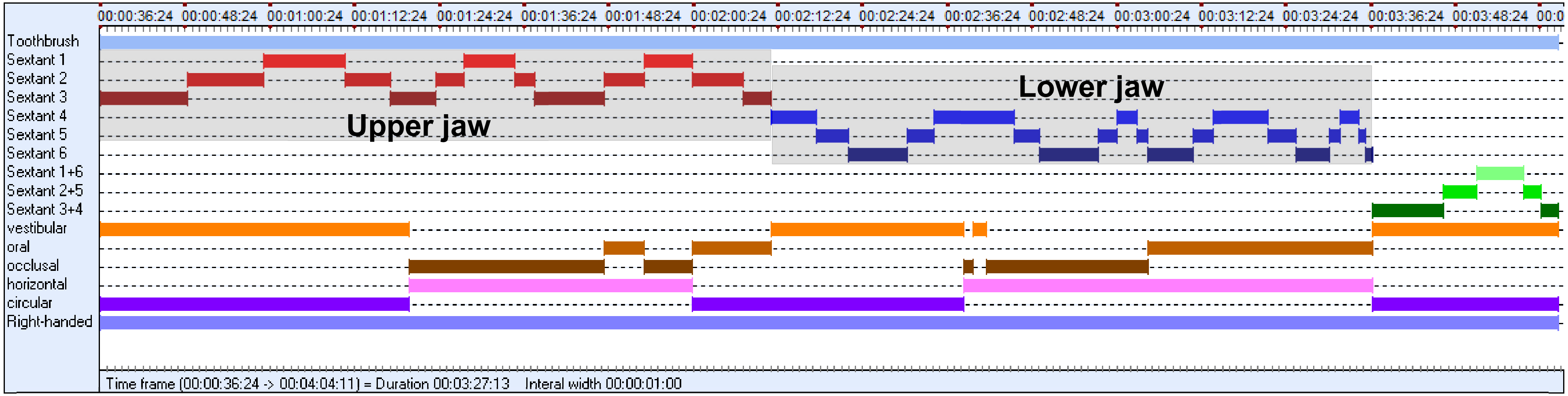


Figure 10a: Systematic brushing pattern.

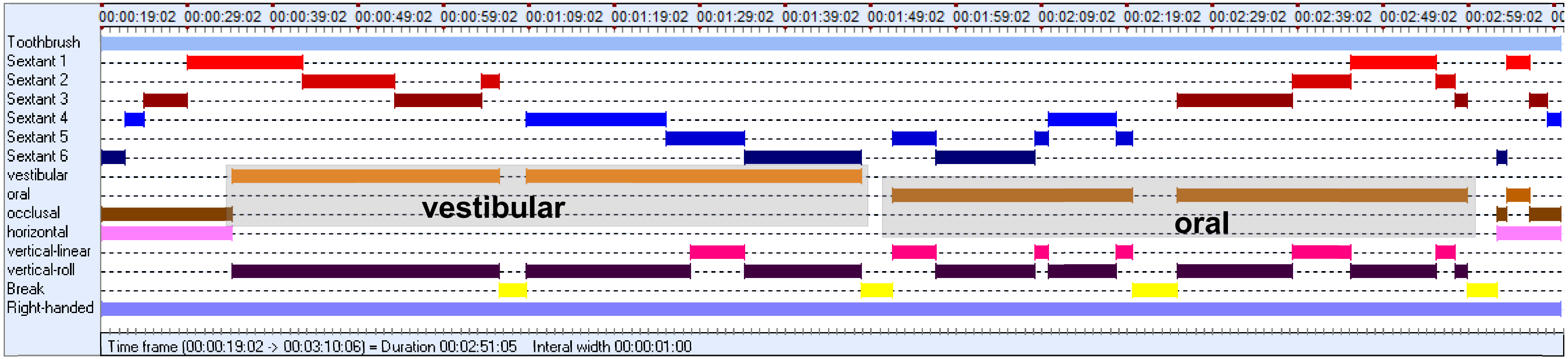


Figure 10b: Systematic brushing pattern.

The grey boxes highlight the reached areas (sextants in the upper and lower jaws, vestibular and oral). Interruptions (breaks) are indicated by the yellow bars. Figure 10a shows that all the sextants (sextant 1 to sextant 6) were reached (red and blue bars), and first the upper, then the lower jaw was reached. Figure 10b shows that the vestibular surfaces were brushed first, followed by the oral surfaces.

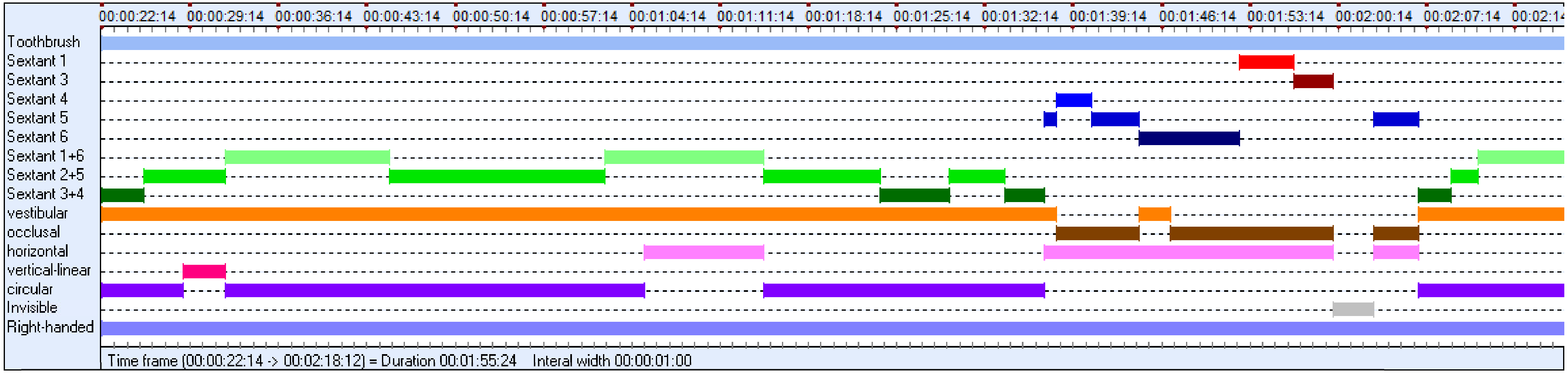


Figure 11a: Unstructured brushing pattern.

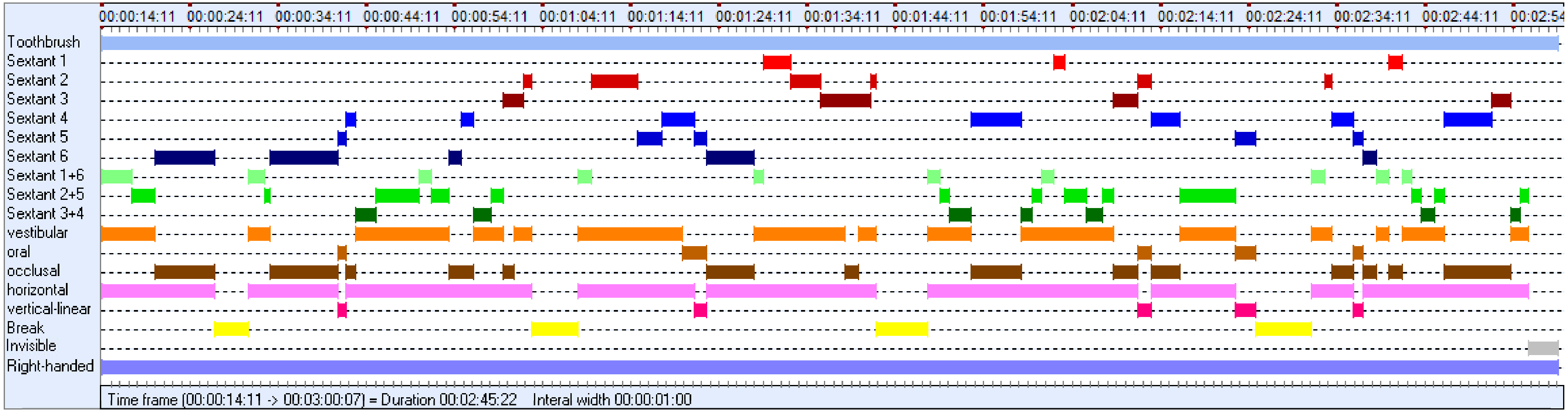


Figure 11b: Unstructured brushing pattern.

Neither a systematic nor a sequential movement pattern could be detected. Figure 11a shows rare changes between sextants and longer phases of the Fones technique [Fones, 1921] (indicated by the simultaneous presence of green, orange and purple bars). The oral tooth surfaces were not reached. Figure 11b shows numerous short events and frequent alternations between the upper and lower jaws.

2.6 Agreement of observations

2.6.1 Plaque scores

To confirm the reproducibility of the plaque scores, the kappa coefficients between two investigators (N.S. and T.W.) were calculated using SPSS. The strength of agreement was determined according to the classification system of Landis and Koch [1977] (tab. 7).

Table 7 Classification of kappa coefficients according to the system of Landis and Koch [1977].

Kappa coefficient	Strength of agreement
<0.00	Poor
0.00–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost Perfect

Three calibrations were performed to determine the interrater agreement for recording the plaque index. These calibrations were performed between an experienced investigator (N.S.) and the clinical investigator (T.W.). The first calibration was performed before the study began, using 10 volunteers not involved in the study with a total of 549 test points. The second calibration was performed after 33 participants had been examined, using 3 volunteers not involved in the study (166 test points), and the third calibration was performed after 66 participants had been examined, using 3 volunteers not involved in the study. The strength of agreement was almost perfect (tab. 8).

Table 8 Interrater agreement for recording the plaque index scores (PI) according to Silness and Loe [1964]. Calibration procedure: (I) 10 volunteers before the study began; (II) 3 volunteers after 33 participants had been examined; and (III) 3 volunteers after 66 participants had been examined.

Plaque score, first calibration							
				N.S.			
	PI	0	1	2	3	total	Kappa
T.W.	0	139	3	0	0	142	0.90
	1	6	126	13	0	145	
	2	0	13	233	2	248	
	3	0	0	0	14	14	
	total	145	142	246	16	549	
Plaque score, second calibration							
				N.S.			
	PI	0	1	2	3	total	Kappa
T.W.	0	9	0	0	0	9	0.82
	1	0	15	1	0	16	
	2	1	6	125	1	133	
	3	0	0	2	6	8	
	total	10	21	126	7	166	
Plaque score, third calibration							
				N.S.			
	PI	0	1	2	3	total	Kappa
T.W.	0	44	0	0	0	44	0.95
	1	1	27	1	0	29	
	2	0	2	85	0	87	
	3	0	0	1	5	6	
	total	45	29	87	5	166	

2.6.2 Video analysis

Both examiners (J.I. and T.W.) participated in the development of an appropriate coding system in INTERACT and the definition of the variables of interest. Therefore, 10 videos were initially examined and discussed to test the newly defined variables, to account for (where appropriate) events that were not considered and to minimise unknown complications before the evaluation began.

To ensure that our procedures were replicable [Bakeman and Gottman, 1997b], all the videos were independently analysed by another observer (J.I.) to confirm the interrater agreement. The intrarater agreement (T.W.) was measured twice: after training but before the analysis began and after the completion of the analysis. The agreements were determined by calculating the kappa coefficient with a time gap to the end of the clinical investigation. The calculations were performed with INTERACT.

The determination of the interrater agreement revealed that the variable *jiggling* exhibited insufficient consistency. Therefore, the variable *jiggling* was converted to *horizontal-linear* and was not considered in the following analysis.

2.6.2.1 Kappa calculation with INTERACT

Most of the coded toothbrushing events included time information (start time, end time and duration). A sequence of these codes resulted in timed-event sequential data. The observer agreement for such data cannot be calculated using the "traditional" Cohen's kappa.

INTERACT offers the possibility of comparing timed-event sequential data [Bakeman et al., 2009] from multiple observers based on a kappa coefficient calculation. According to the help file of INTERACT, *"[…]the Kappa coefficient calculated by INTERACT takes care about the fact that a coder could have given more than one code at a time whereas the standard Cohen's Kappa does not and it also takes care of cases where one coder has detected certain behaviour whereas the other one has detected nothing."* [Mangold, 2011].

Before initiating the kappa calculation, two parameters of tolerances could be set. For codes with duration (e.g., total brushing duration), their percentage overlap could be adjusted. The preset tolerance for these time-based events in INTERACT was 50%. For single-time events (events without duration, e.g., a flossing event in a sextant), an interval could be defined in which the matching code, should it appear, would be counted as a match. At the beginning of the kappa analysis, INTERACT attempts to identify matching pairs based on the entered parameters. The algorithm makes six passes through the data sets, which were described by Bakeman et al. [2009]:

1. *"[Overlaps:] Two events are linked if an identical event in the other observer's record overlaps P% of the current event's duration, even if the other observer's event is already unlinked.*
2. *[Tolerance matches:] Two events are linked if the difference in onset times between the current event and an identical event in the other observer's record falls within the tolerance window (i.e., is less than or equal to the stated tolerance), and if the other observer's events is yet unlinked.*
3. *[Unlinked events within tolerance:] Two events are linked if the difference in onset times between the current event and an event in the other observer's record falls within the tolerance window and if the other observer's event is yet unlinked. If multiple events fall within the tolerance window, then the first is selected.*
4. *[Any events within tolerance:] Two events are linked if the difference in onset times between the current event and an event in the observer's record falls within the tolerance window, even if the other observer's event is already linked. If multiple events fall within the tolerance window, then the last is selected.*
5. *[Other events:] Any remaining unlinked events are linked if a current event in the observer's record overlaps P% of the current event's duration.*
6. *Any remaining unlinked events are linked to a nil event of the other observer […]."*

2.6.2.2 Intrarater agreement

In the beginning of the analysis, 10 videos were selected randomly (http://www.random.org/) and were analysed two times by the same examiner (T.W.) to calculate the intrarater agreement before analysing all the videos (tabs. 9 and 10). To determine whether drift occurred when assessing the videos, after the analysis of all the videos had been completed, the same 10 videos were analysed again to reconfirm the intrarater agreement (tabs. 11 and 12). The calculations of consistency were performed using INTERACT, and the following parameters were selected: Codes with duration were registered if they overlapped at least 85% and if their start was within a tolerance of 24 fps (= 0.96 seconds). The selection of overlapping was deactivated for codes without duration (selectively occurring), and a start tolerance of 2 seconds was set. The observer agreement for coded classes is presented as the kappa coefficient value, and the observer agreement for single codes is presented as the % agreement. According to the code of interest, the observer agreement was calculated as the sum of matched pairs within tolerances divided by the total number of the observed code. Two values of % agreement are presented; one is the result of the comparison between the first and second (respectively third) observations, and the other is the result of the comparison between the second (respectively third) and first observations.

Table 9 Intrarater agreement for codes with duration before the analysis began; 10 videos were analysed a second time; events were registered only if they overlapped at least 85% and if their onset was within a start tolerance of 0.96 seconds.

Class (grey) / Code (white)	Sum of coded events		Sum of matched pairs within tolerances	Agreement	
	First evaluation	Second evaluation		[%]	Kappa coefficient
Handedness					1
Right	10	10	10	100/100	
Left	0	0	0	100/100	
Brushing stroke					0.96
Horizontal	59	59	58	98.3/98.3	
Circular	36	34	34	94.4/100	
Unspecific	4	6	4	100/66.7	
Vertical-roll	11	11	11	100/100	
Vertical-linear	21	22	21	100/95.5	
Tooth surfaces					0.91
Vestibular	71	72	70	98.6/97.2	
Occlusal	77	79	74	96.1/93.7	
Oral	34	31	28	82.4/90.3	
Sextant					0.92
Sextant 1	40	39	38	95/97.4	
Sextant 2	54	59	52	96.3/88.1	
Sextant 3	42	44	41	97.6/93.2	
Sextant 4	72	64	63	87.5/98.4	
Sextant 5	57	63	55	96.5/87.3	
Sextant 6	63	65	63	100/96.9	
Sextant 1_6	25	26	24	96/92.3	
Sextant 2_5	47	44	41	87.2/93.2	
Sextant 3_4	28	23	22	78.6/95.7	
Flossing technique					1
Horizontal	5	5	5	100/100	
In-and-out	3	3	3	100/100	
Vertical	2	2	2	100/100	
Cleaning agent					1
Toothbrush	10	10	10	100/100	
Floss	5	5	5	100/100	

Table 10 Intrarater agreement for codes without duration before the analysis began; 10 videos were analysed a second time; events were registered only if their onset was within a start tolerance of 2 seconds.

Number of flossed interproximal spaces in each sextant					
	Sum of coded events		Sum of matched pairs within tolerance	Agreement	
Area	First evaluation	Second evaluation		Code [%]	Class Kappa coefficient
Sextant 1	12	12	11	91.7/91.7	0.89
Sextant 2	55	58	54	98.2/93.1	
Sextant 3	7	7	7	100/100	
Sextant 4	14	13	12	85.7/92.3	
Sextant 5	30	31	30	100/96.8	
Sextant 6	13	13	12	92.3/92.3	

Table 11 Intrarater agreement for codes with duration after the analysis had been completed; 10 videos were analysed for a third time; events were registered only if they overlapped at least 85% and if their onset was within a start tolerance of 0.96 seconds.

Class (grey) Code (white)	Sum of coded events		Sum of matched pairs within tolerances	Agreement	
	First evaluation	Third evaluation		[%]	Kappa coefficient
Handedness					1
Right	10	10	10	100/100	
Left	0	0	0	100/100	
Brushing stroke					0.98
Horizontal	58	58	57	98.3/98.3	
Circular	36	35	35	97.2/100	
Unspecific	6	6	6	100/100	
Vertical-roll	11	11	11	100/100	
Vertical-linear	21	22	21	100/95.5	
Tooth surfaces					0.87
Vestibular	76	74	71	93.4/96	
Occlusal	76	81	72	94.7/88.9	
Oral	33	29	28	84.9/96.6	
Sextant					0.86
Sextant 1	47	43	39	83/90.7	
Sextant 2	48	63	46	95.8/73	
Sextant 3	43	44	40	93/90.9	
Sextant 4	69	65	61	88.4/93.9	
Sextant 5	55	58	50	90.9/86.2	
Sextant 6	61	68	60	98.4/88.2	
Sextant 1_6	32	27	25	78.1/92.6	
Sextant 2_5	50	44	40	80/90.9	
Sextant 3_4	30	23	23	76.7/100	
Flossing technique					1
Horizontal	5	5	5	100/100	
In and out	3	3	3	100/100	
Vertical	2	2	2	100/100	
Cleaning agent					1
Toothbrush	10	10	10	100/100	
Floss	5	5	5	100/100	

Table 12 Intrarater agreement for codes without duration after the analysis had been completed; 10 videos were analysed for the third time; events were registered only if their onset was within a start tolerance of 2 seconds.

Number of flossed interproximal spaces in each sextant					
	Sum of coded events		Sum of matched pairs within tolerance	Agreement	
Area	First evaluation	Third evaluation		Code [%]	Class Kappa coefficient
Sextant 1	12	12	12	100/100	0.98
Sextant 2	59	59	59	100/100	
Sextant 3	7	7	7	100/100	
Sextant 4	13	13	13	100/100	
Sextant 5	31	31	31	100/100	
Sextant 6	13	13	12	92.3/92.3	

2.6.2.3 Interrater agreement

Every video was analysed by both examiners (T.W. and J.I.). The interrater agreement was determined in INTERACT using both complete data sets after the video analysis had been completed. For the kappa calculation, the same parameters used for the intrarater agreement calculation were set: Codes with duration were registered as matched if they overlapped at least 85% and if their start was within a tolerance of 24 fps (0.96 seconds) (tab. 13). The selection of overlapping was deactivated for codes without duration (selectively occurring), and a start tolerance of 2 seconds was set (tab. 14). The observer agreement for coded classes is presented as the kappa coefficient value, and the observer agreement for single codes is presented as the % agreement. According to the code of interest, the observer agreement was calculated as the sum of matched pairs within tolerances divided by the total number of the observed code. Two values of % agreement are presented; one is the result of the comparison between the observational data of the first (T.W.) and second (J.I.) examiners, and the other is the result of the comparison between the observational data of the second (J.I.) and first (T.W.) examiners.

Table 13 Interrater agreement for codes with duration; every video was analysed by both examiners; events were registered only if they overlapped at least 85% and if their onset was within a start tolerance of 0.96 seconds.

	Sum of coded events		Sum of matched pairs within tolerances	Agreement	
Class (grey) Code (white)	Examiner 1 (T.W.)	Examiner 2 (J.I.)		[%]	Kappa coefficient
Handedness					1
Right	98	98	98	100/100	
Left	19	19	19	100/100	
Brushing stroke					0.67
Horizontal	775	860	679	87.6/79	
Circular	437	441	376	86/85.3	
Unspecific	62	31	9	14.5/29	
Vertical-roll	65	70	48	73.9/68.6	
Vertical-linear	349	263	219	62.8/83.3	
Tooth surfaces					0.72
Vestibular	770	689	650	84.4/94.3	
Occlusal	900	1009	781	86.8/77.4	
Oral	432	392	311	72/79.3	
Sextant					0.83
Sextant 1	481	459	412	85.7/89.8	
Sextant 2	634	547	479	75.6/87.6	
Sextant 3	403	438	370	91.8/84.5	
Sextant 4	551	556	493	89.5/88.7	
Sextant 5	574	506	465	81/91.9	
Sextant 6	649	637	581	89.5/91.2	
Sextant 1_6	328	384	300	91.5/78.1	
Sextant 2_5	559	549	458	81.9/83.4	
Sextant 3_4	366	434	341	93.2/78.6	
Flossing technique					0.45
Horizontal	63	73	47	74.6/64.4	
In-and-out	89	70	56	62.9/80	
Vertical	14	25	11	78.6/44	
Cleaning agent					1
Toothbrush	103	103	103	100/100	
Floss	47	47	47	100/100	

Table 14 Interrater agreement for codes without duration; every video was analysed by both examiners; events were registered only if their onset was within a start tolerance of 2 seconds.

Number of flossed interproximal spaces in each sextant					
	Sum of coded events		Sum of matched pairs within tolerance	Agreement	
Area	Examiner 1 (T.W.)	Examiner 2 (J.I.)		Code [%]	Class Kappa coefficient
Sextant 1	91	99	83	91.2/83.8	0.88
Sextant 2	375	379	355	94.7/93.7	
Sextant 3	78	81	72	92.3/88.9	
Sextant 4	94	93	86	91.5/92.5	
Sextant 5	305	305	295	96.7/96.7	
Sextant 6	83	82	80	96.4/97.6	

2.7 Aggregation of the data and statistical analysis

The total brushing duration was calculated using INTERACT, and the mean value was calculated using SPSS 20 (IBM, Armonk, NY, USA). The effective brushing duration, which was defined as the total brushing duration without special events such as rinsing, spitting or breaks, was calculated in SPSS 20 by summing the brushing duration in each sextant (variables *sextant 1* to s*extant 3_4*).

The handedness of the participants was obvious, but some participants used both hands alternately; therefore, each participant was identified as left- or right-handed depending on the predominantly used hand. The predominantly used hand was the hand used for over 50% of the total brushing duration. The calculation was performed with SPSS 20.

The durations of the different brushing strokes were calculated using INTERACT. To calculate the duration and frequency of a site-specific brushing stroke (e.g., the brushing duration in sextant 1 vestibular with horizontal brushing strokes), the function *co-occurrence filter* in INTERACT was used: several variables could be combined, and their overlap was summed in a new event. Subsequently, these data were imported into SPSS 20, and the primarily performed brushing strokes were calculated. For these calculations, sextant 1, sextant 6 and sextant 1_6 were combined into a new variable, *right side*; sextant 2, sextant 5 and sextant 2_5 were combined into *anterior*; and sextant 3, sextant 4 and sextant 3_4 were combined into *left side*. The brushing stroke performed for the longest time in each area was calculated. The combination of circular strokes on the vestibular surfaces and sextant 1_6, sextant 2_5 or sextant 3_4 represented a special combination of events that was defined as an element of the Fones technique [Fones, 1921].

The starting location, which was generated by INTERACT as part of the data set, was entered into SPSS 20. To ensure comparability of the data regarding earlier studies investigated this issue, the data of the left-handers were inverted (e.g., vestibular right side to vestibular left side). The starting location data from the sextant 1 and sextant 6 were summarised into the right area, the data from the sextant 2 and sextant 5 into the anterior area and the data from the sextant 3 and sextant 4 into the left area.

The frequency of tooth brushing events was calculated using INTERACT. The function *sequence analyses* provides information about the frequency of alternations between two sextants, which is presented as the percentage of the total changes from the originating sextant, and for alternations between the occlusal, oral and vestibular tooth surfaces, which is presented as the percentage of total changes from the originating surface. The frequency distribution of movements with the toothbrush from one area to another was also calculated. An area was defined as the anterior, right or left side and the corresponding tooth surface (oral, occlusal or vestibular).

Whether the floss reached a sextant completely, incompletely or not at all was generated by INTERACT as part of the data set and was entered into SPSS 20. Each combination of flossing technique and reached interproximal space was recoded as a new event in INTERACT using the *co-occurrence filter*. These events were totalled in SPSS 20, and the flossing technique with the maximum value of events was determined as predominantly used flossing technique.

The classification of brushing patterns as sequential, systematic or unstructured was based on the initial visual impression of the timeline charts. A special program for sequential analysis called Generalized Sequential Querier (GSEQ 5.1) [Bakeman and Quera, 2013] was used to analyse the sequential brushing patterns. The INTERACT files for each participant were converted into sequential data interchange standard (SDIS) formatted files with the software ActSds 3.0.3 [Bakeman and Quera, 2008]. As part of this conversion, the unit of time was converted from frames per second to milliseconds. These SDIS files were compiled using GSEQ, and modified sequential data interchange standard (MDS) files resulted. Every MDS file was modified using GSEQ; we used the command *remove* to select only the codes of interest and the command *event* to remove the time from the data, resulting in a timeless sequence of events. Then, the function N-way table in GSEQ was used to detect 4-event chains within the entire event sequence. The exported data indicated the frequency of the detected 4-event chains. If the number of the most frequent chain was 3 or higher, this indicated a sequential brushing pattern.

The PI values were transferred from CRF to SPSS 20. For each participant, the mean, maximum, oral and vestibular plaque scores were calculated using SPSS 20.

The statistical analysis was performed with SPSS 20. The data were checked for normal distribution (Kolmogorov-Smirnov test). Statistically significant deviations were found for the brushing duration on the right side, oral surfaces and for the oral PI values. The median, minimum and maximum values of these data were provided.

The Wilcoxon test and the Friedman test were performed to determine whether participants brushed for different durations in different areas (upper and lower jaws, vestibular and oral surfaces, and left, right and anterior sides) and whether their oral hygiene level differed between these areas.

Additionally, we analysed whether there was an association between the effective brushing duration and the oral hygiene level. Therefore, the brushing duration and plaque index were correlated (Spearman), categorised (brushing duration < 2 minutes, 2 to < 3 minutes or ≥ 3 minutes; PI 0.5 to < 1; 1 to < 1.5; 1.5 to < 2 or 2 to < 2.5) and analysed using the chi-square test.

The self-reported brushing duration and the video-analysed brushing duration were tested for correlation. For this calculation, the video-analysed brushing duration was classified into the same categories as the brushing duration on the questionnaires (30 seconds, 1 minute, 1.5 minutes, 2 minutes, 3 minutes, and >3 minutes). The correlation was tested using Kendall's tau-b test.

The participants were divided into two groups: those who brushed systematically and those who brushed non-systematically (following a sequential or unstructured pattern). The data from every group were checked for normal distribution (Kolmogorov-Smirnov test). Statistically significant deviations were found for the variables maximum PI and mean oral PI. The Mann-Whitney U test was performed to detect differences between the two groups regarding the mean plaque index (total, oral, vestibular, upper jaw and lower jaw) and the maximum total plaque index. A one-way ANOVA was performed to detect differences in the effective brushing duration (total; oral, vestibular and occlusal; upper jaw and lower jaw; right side, left side and anterior) between the two groups.

The level of significance was set to 0.05.

All the other data are presented descriptively.

3 RESULTS

3.1 Description of the investigated group

A total of 101 participants were included. Fifty-eight participants were female, and 43 were male. The average age was 18.9 ± 0.3 years. The parents' formal education level of 20 participants was low, 22 had a middle level of formal education, 54 had a high level of formal education, and 5 participants were unable to provide any information about their parents' education level.

3.2 Results of the questionnaires

3.2.1 Oral hygiene education

Eighty-two participants reported that they were educated in a brushing technique, two participants provided no information, and 17 participants had never been educated in a brushing technique. Figure 12 shows the participants' sources of brushing technique education. The brushing technique questions in the questionnaires were free-response; therefore, multiple answers were possible and were provided by 16 participants. Of the 56 participants who were educated by a dentist, 18 were educated by a dentist at school and 1 was educated by a representative of the health insurance fund at school.

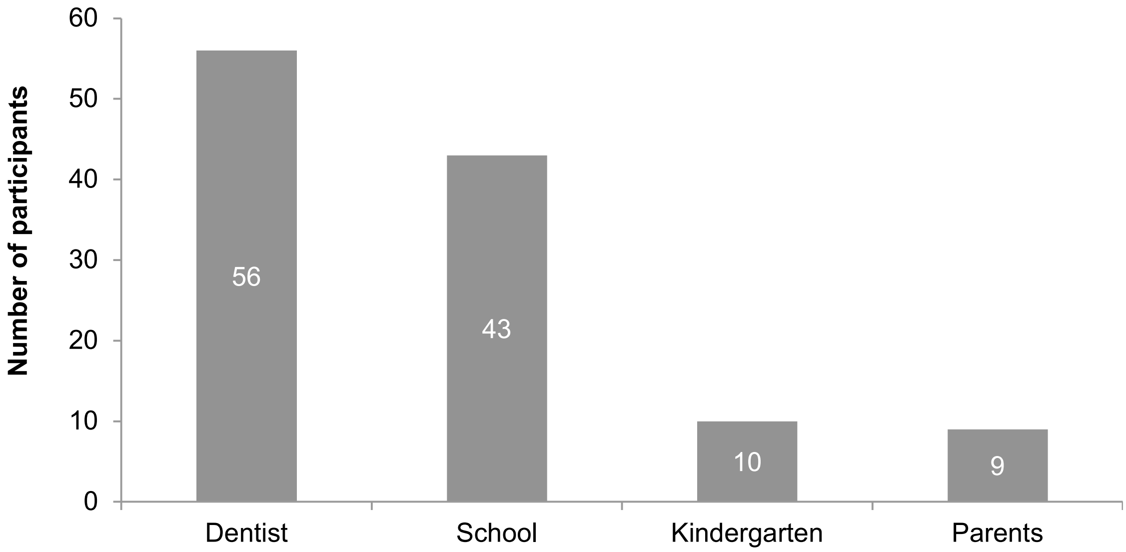


Figure 12: Oral hygiene education. Multiple answers were possible; n = 82.

3.2.2 Brushing techniques that were taught

Seventy-three participants provided information about the brushing technique in which they had been instructed (fig. 13). Multiple answers were possible. The most common brushing technique was circular or a combination of circular and other techniques (n = 40). The other reported brushing techniques were as follows: from 'red to white' (n = 10), the KAI technique (n = 8), a systematic technique (n = 2), the Bass technique (n = 1) [Bass, 1954;Hellwege, 1999] and a 'screw technique' (n = 1). Seventeen participants provided unspecific information, e.g., brushing 'in a normal way', 'hard to put into words', and 'all teeth have to be brushed'. The 'red to white' brushing technique involves a vertical brushing movement from the gum to the dental crown. The 'screw technique' is described nowhere.

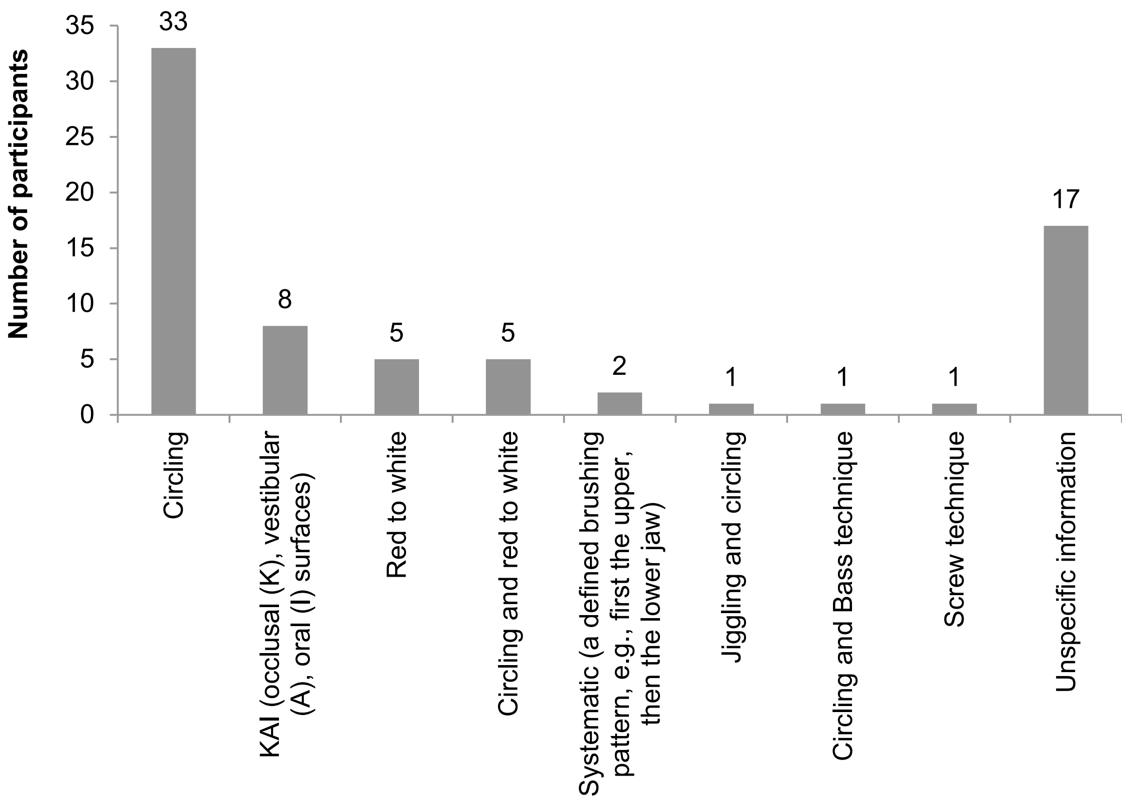


Figure 13: Brushing techniques that were taught. Multiple answers were possible; n = 73.

3.2.3 Frequencies of daily toothbrushing

Ninety-seven participants reported their frequency of daily toothbrushing. Most of the participants brushed twice per day (n = 71). Nearly equal numbers of participants brushed their teeth once per day (n = 11) or three or more times per day (n = 10). Four participants brushed several times per week, and 1 participant brushed less than once per week.

3.2.4 Daily time of toothbrushing

All the participants (n = 101) provided information about the time of day when they brushed their teeth (fig. 14). The combination of ‘after waking up/before breakfast’ and ‘before going to bed’ (n = 33) and the combination of ‘after breakfast’ and ‘before going to bed’ (n = 33) were the most common answers. Only 16 participants stated that they brushed after breakfast, at bedtime and one or more additional time points, such as after snacks, dinner, lunch or other.

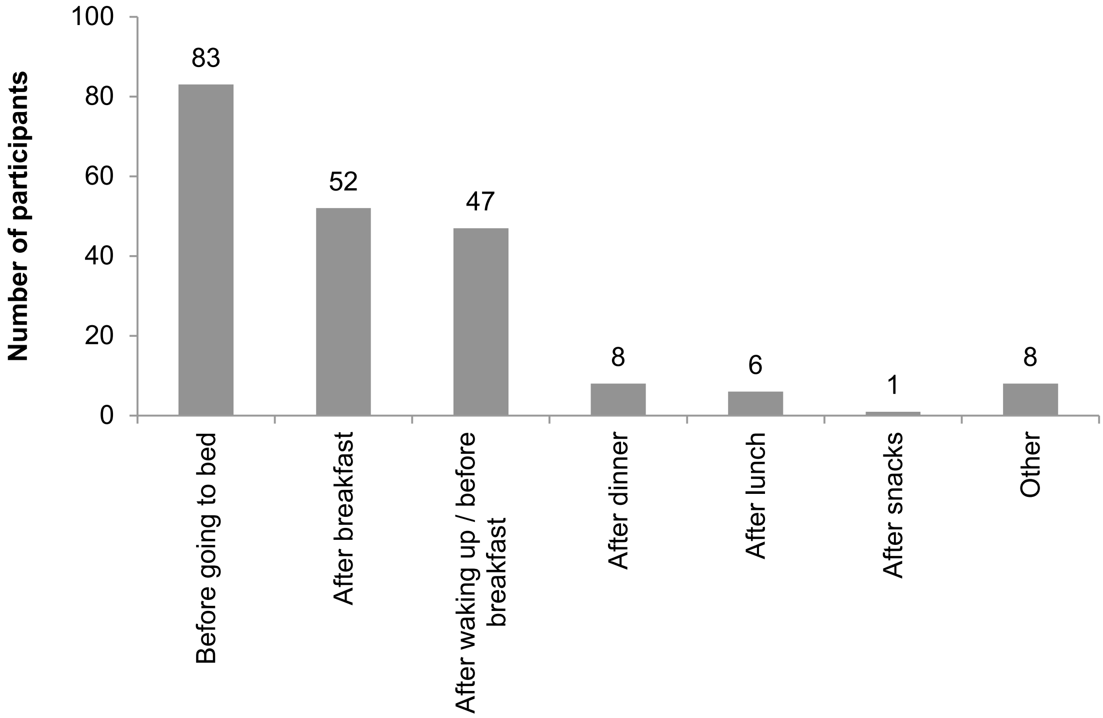


Figure 14: Daily time of toothbrushing. Multiple answers were possible; n = 101.

3.2.5 Self-reported brushing duration

One hundred participants provided information about their brushing duration (tab. 15). Most reported brushing for 2 minutes or longer (n = 76). Only one participant reported brushing less than one minute.

Table 15 Self-reported brushing duration.

Reported brushing duration	Number of participants
Approx. 30 seconds	1
Approx. 1 minute	6
Approx. 1.5 minutes	17
Approx. 2 minutes	38
Approx. 3 minutes	26
Longer than 3 minutes	12
No information reported	1

3.2.6 Good and bad oral hygiene levels

According to the *good* and *bad oral hygiene level* classifications of the DMS IV [Micheelis, 2006b], the results of the present study showed that 37% of the participants had a good oral hygiene level and 58% had a bad oral hygiene level. Five percent provided incomplete data and were not included in the analysis.

3.2.7 Oral hygiene aids

One hundred participants stated that they used a manual toothbrush to clean their teeth (fig. 15), 7 of whom brushed without toothpaste. One participant fulfilled the inclusion criterion ‘no regular use of a powered toothbrush’ but did not check either box concerning toothbrush type (manual or powered) in the questionnaires. Forty-two participants also used oral hygiene aids for interdental cleaning (37 participants used dental floss, and 5 participants used interproximal brushes). The combination of a toothbrush and other oral hygiene aids (e.g., a toothpick, dental water jet, or sugar-free chewing gum) was reported by one-third of the participants.

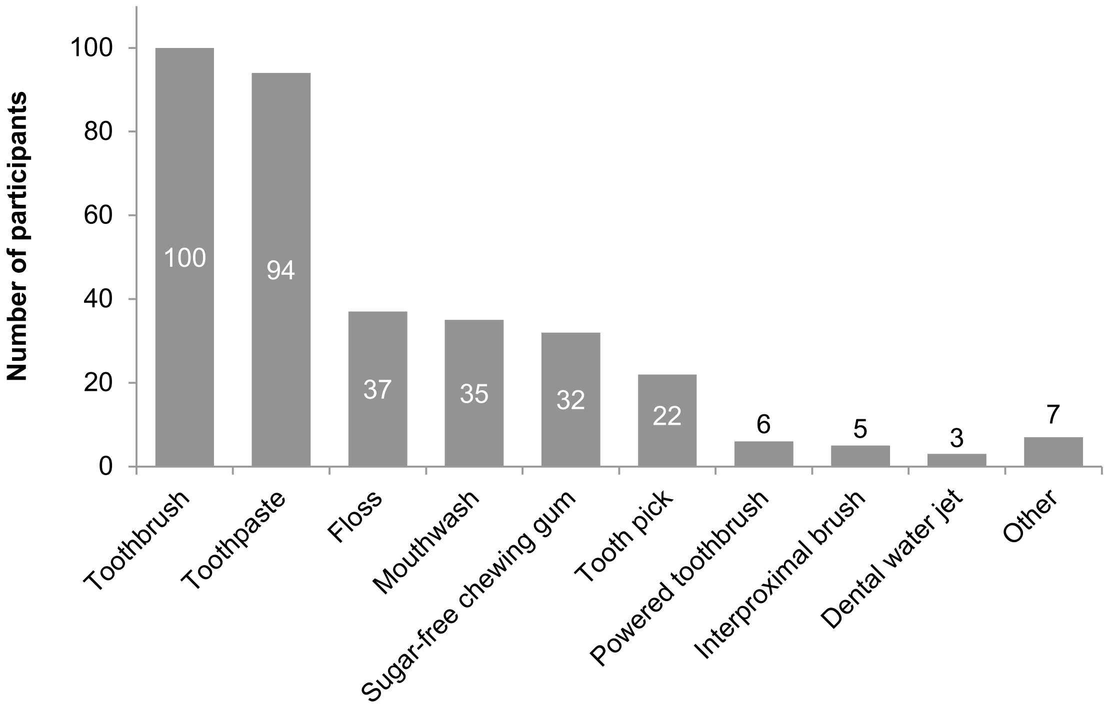


Figure 15: Oral hygiene aids used by the participants. Multiple answers were possible; n = 101.

3.3 Results of the video analysis

3.3.1 Toothbrushing habits

3.3.1.1 Total brushing duration and effective brushing duration

The mean total brushing duration was 162.5 ± 73.9 seconds. Two-thirds of the participants brushed for 2 minutes or longer, and only 8 participants brushed less than 1.5 minutes (fig. 16). After the subtraction of special events, such as rinsing or spitting, the effective brushing duration was 156.0 ± 71.1 seconds, which exhibited 96% correspondence with the total brushing duration (fig. 17).

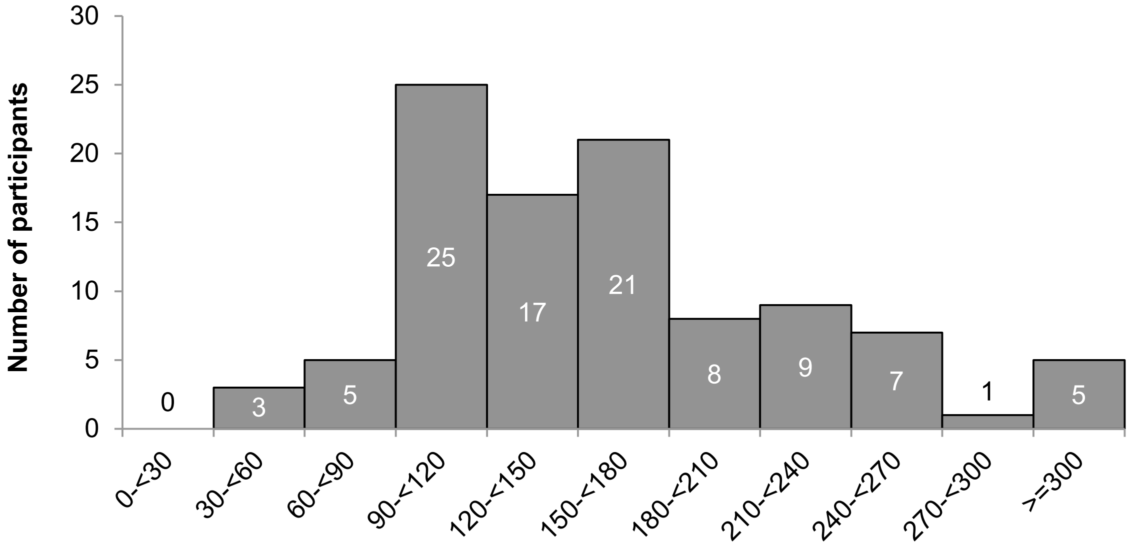


Figure 16: Total brushing duration categorised into 30-second increments; n = 101.

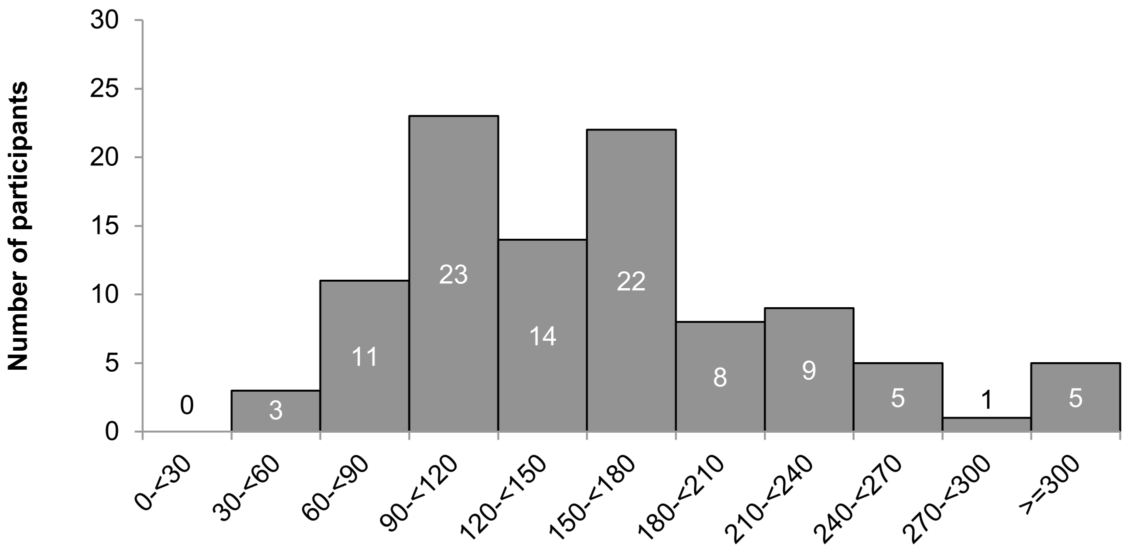


Figure 17: Effective brushing duration categorised into 30-second increments; n = 101 [Winterfeld et al., 2015] (with permission of Springer Science+Business Media).

There were few differences between the brushed areas: the brushing duration was 75.9 ± 35.4 seconds in the upper jaw and 80.2 ± 38.3 seconds in the lower jaw ($p \leq 0.05$). The right side was brushed for 52.0 ± 26.0 seconds (minimum: 11.6 seconds; maximum: 128.9 seconds; median: 46.0 seconds), the left side for 48.8 ± 26.0 seconds and the anterior area for 55.3 ± 29.0 seconds (n.s.).

A distinct difference was found between the brushing duration on the oral and vestibular tooth surfaces: the participants brushed the vestibular surfaces for 72.1 ± 31.8 seconds, two and a half times longer than the oral surfaces (27.1 ± 27.8 seconds; minimum: 0 seconds; maximum: 173.6 seconds; median: 22.0 seconds; $p \leq 0.001$). The occlusal surfaces were brushed for 56.7 ± 33.4 seconds.

There was a correlation between the observed total brushing duration and the reported total brushing duration ($r = 0.43$; $p \leq 0.01$).

3.3.1.2 Handedness

Twelve participants brushed their teeth with the left hand. The variable handedness was considered in the analysis of the starting location, for which the data for left-handers were inverted.

3.3.1.3 Reached areas

The areas reached by the toothbrush varied. The vestibular surfaces of the anterior and posterior teeth were reached by nearly every participant, but only half of the participants reached the oral surfaces of the upper and lower posterior teeth. The oral surfaces of the lower anterior teeth were reached by 86 participants, and the oral surfaces of the upper anterior teeth were reached by 74 participants (fig. 18).

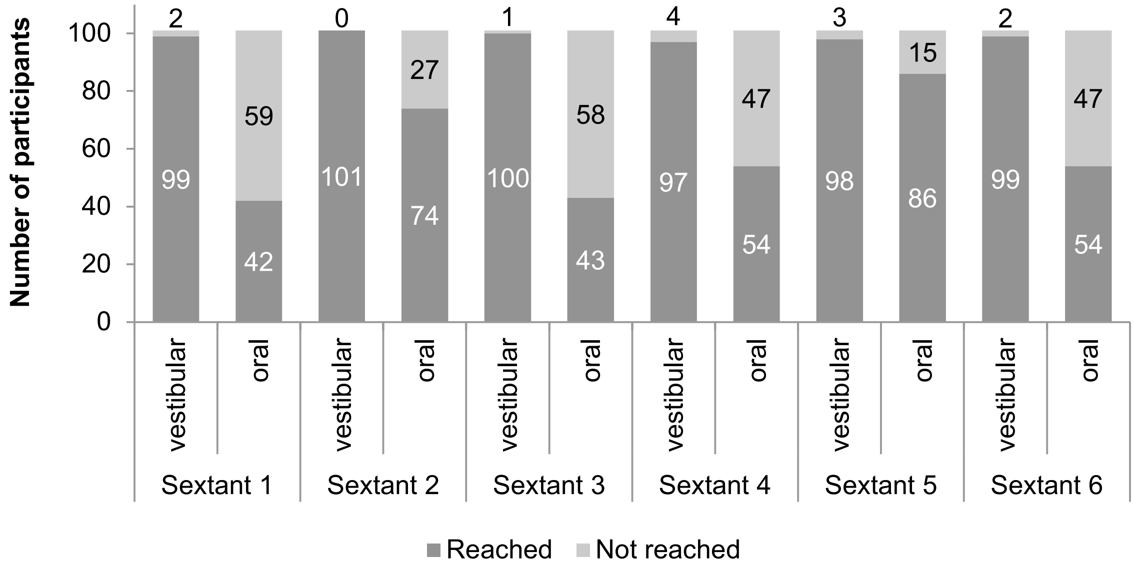


Figure 18: Areas reached by the toothbrush (sextants and tooth surfaces); n = 101.

The jaws were divided into 12 areas (the oral and vestibular surfaces of sextants 1–6). Approximately one quarter of the participants reached all 12 areas (fig. 19).

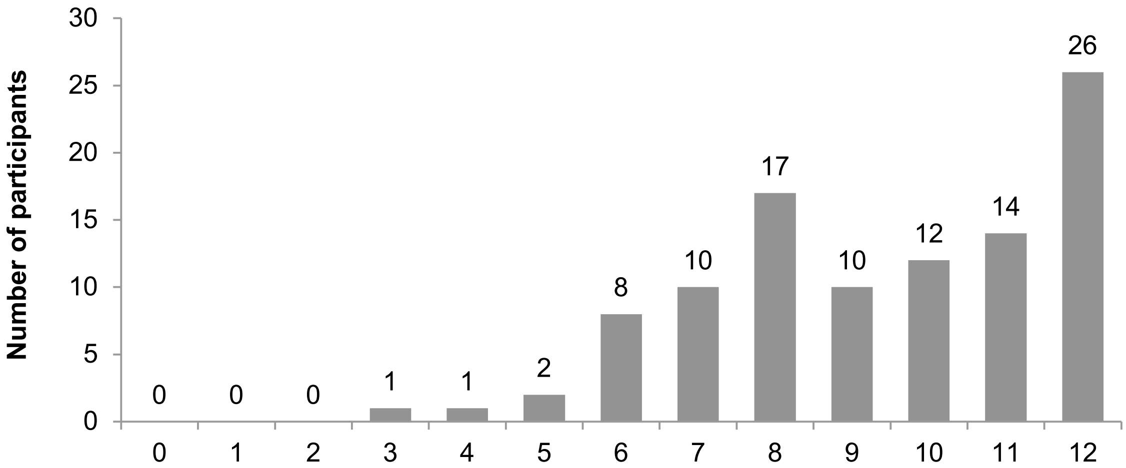


Figure 19: Areas reached by the toothbrush; 0–12 indicate the numbers of reached areas (12 = all the oral and vestibular surfaces in every sextant were reached); n = 101.

3.3.1.4 Brushing strokes

The type of brushing movement performed for the longest time was the horizontal brushing stroke (90.1 ± 50.5 seconds), followed by the circular stroke (45.0 ± 41.0 seconds). Vertical-linear strokes (11.2 ± 16.3 seconds) and vertical-roll strokes (6.9 ± 30.7 seconds) were performed for shorter periods. Unspecific brushing strokes were performed for negligible periods (2.6 ± 6.3 seconds).

The vestibular surfaces of the anterior and posterior teeth were predominantly brushed with circular and horizontal-linear strokes (fig. 20). The oral surfaces of the posterior teeth were predominantly brushed with horizontal-linear strokes, and the oral surfaces of the anterior teeth with vertical-linear strokes.

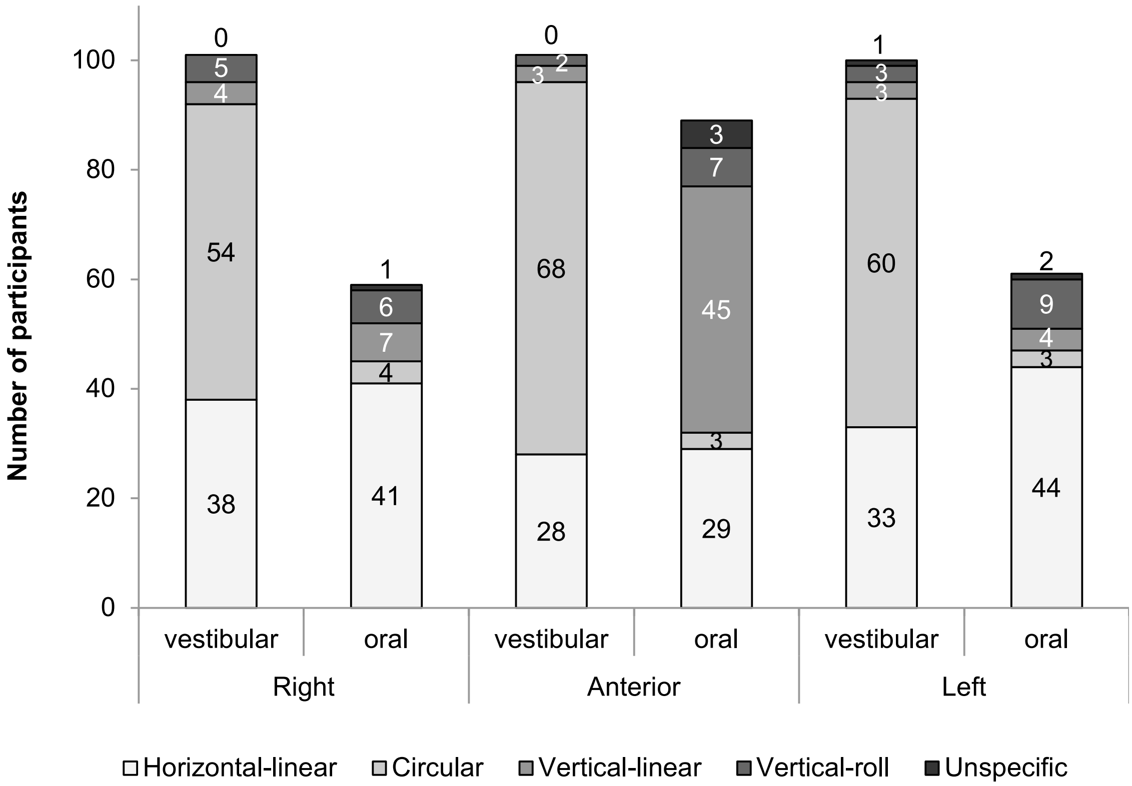


Figure 20: Most-frequently performed brushing strokes stratified by sextant and surface; a number of participants < 101 indicates that not every participant brushed this area; n = 101 [Winterfeld et al., 2015] (with permission of Springer Science+Business Media).

Circular brushing movements on both closed jaws were defined as an element of the Fones technique [Fones, 1921]. Seventy-nine participants performed toothbrushing according to elements of this technique; 85% of them performed the technique during 10 to 50% of the effective brushing duration (tab. 16).

Table 16 Numbers of participants who brushed according to elements of the Fones technique [Fones, 1921] (circular brushing movements on both closed jaws) classified according to the percentage of the effective brushing duration.

Percentage of effective brushing duration performed with the Fones technique	Number of participants
<10%	11
10 to <30%	33
30 to <50%	30
>50%	5
Total participants	79

3.3.1.5 Starting location

The starting location data were inverted for the left-handers (n = 12). The most frequent starting locations were the occlusal surfaces of the right (n = 24) and left sides (n = 25), followed by the vestibular surfaces of the left side (n = 20) and of the anterior teeth (n = 18) (fig. 21).

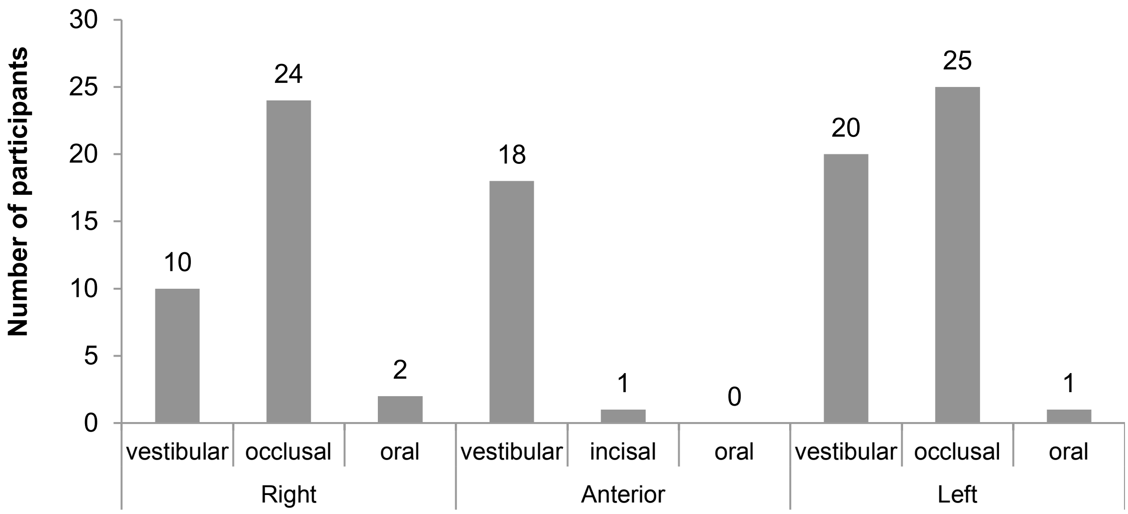


Figure 21: Starting location of tooth brushing (data of left-handers were inverted) stratified by side (right, anterior or left) and tooth surface (vestibular, occlusal or oral); n = 101.

Additionally, the area that was brushed immediately after the starting location was analysed (tab. 17) according to the method of Macgregor and Rugg-Gunn [1979a]. Most of the participants who started brushing in the anterior vestibular areas then moved to the left vestibular areas (n = 15). The participants who began brushing on the left vestibular surfaces predominantly moved to the anterior vestibular areas (n = 18). Equal numbers of participants who started in the occlusal areas of the left (n = 7) and right (n = 7) sides moved to the anterior incisal areas. Ten participants who started in the occlusal areas of the right side moved to the left, and vice versa. The most frequent alternation from the starting area was to the anterior vestibular areas (n = 30).

Table 17 Frequency distribution of the sequences in which tooth surfaces were brushed first (starting location) and second, according to Macgregor and Rugg-Gunn [1979a] (data from left-handers were inverted). Areas not brushed first or second were omitted. Vest = vestibular; occl = occlusal; inc = incisal; n = 101.

			Starting location								
Area			Right			Anterior		Left			
			vest	occl	oral	vest	inc	vest	occl	oral	total
Following	Right	vest	0	1	0	1	0	1	1	0	4
		occl	3	2	0	0	1	0	10	0	16
		oral	0	1	0	0	0	0	0	0	1
	Anterior	vest	6	1	0	2	0	18	3	0	30
		inc	0	7	0	0	0	0	7	0	14
		oral	0	1	2	0	0	0	2	0	5
	Left	vest	1	1	0	15	0	1	2	0	20
		occl	0	10	0	0	0	0	0	1	11
	total		10	24	2	18	1	20	25	1	101

3.3.1.6 Brushing events

The participants frequently alternated between sextants and tooth surfaces during toothbrushing. The mean number of these brushing events was 45.1 ± 22.4. The vestibular surfaces in every sextant were approached more often (20.3 ± 11.2) than the oral surfaces (7.0 ± 6.0).

Alternation frequency from one sextant to another

Overall, alternations between the sextants within a jaw occurred frequently (fig. 22). After the first and third sextants in the upper jaw were brushed, the second sextant was primarily visited. Proceeding from the second sextant, the first and third sextants were frequented equally.

In the lower jaw, after the fourth and sixth sextants were brushed, the neighbouring and opposite sextants were visited equally. After the anterior teeth were brushed, the left and right sides were most frequently brushed. Diagonal alternations or alternations between the jaws were distinctly rarer, with an accumulation of changes from the sixth to the first sextant. Participants with both dental arches closed most frequently brushed from posterior teeth to anterior teeth and from anterior teeth to the left and right sides (not shown in figure 22).

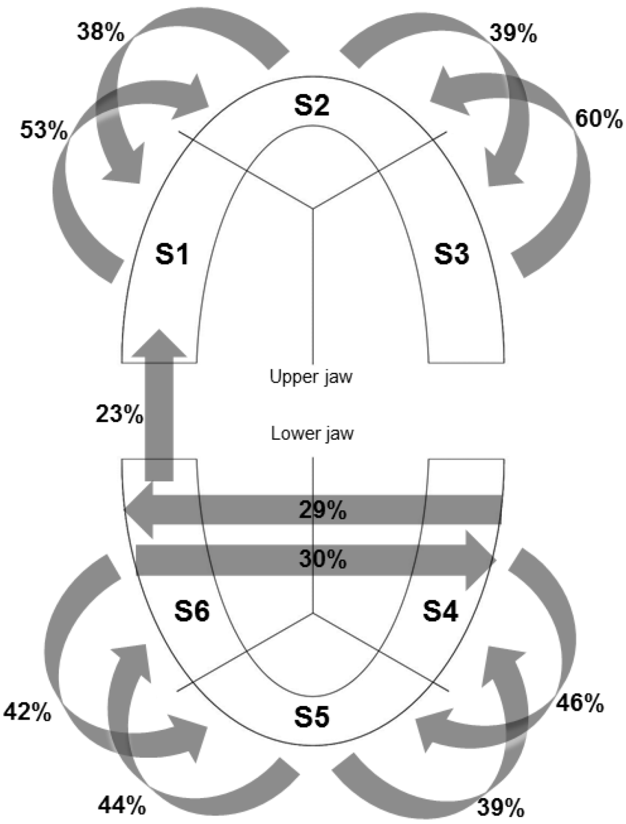


Figure 22: Schematic illustration of the preferred alternations from one sextant to the next. The frequency is shown as the percentage of all the possible alternations originating from a given sextant. There was no differentiation regarding surface (oral, vestibular, or occlusal) [Winterfeld et al., 2015] (with permission of Springer Science+Business Media).

Alternation frequency from one surface to another

Regarding the tooth surfaces, the participants most frequently alternated from vestibular surfaces to occlusal surfaces (87% of all possible changes originated from vestibular surfaces; 502 movements) and from occlusal surfaces to vestibular surfaces (63% of all possible changes originated from occlusal surfaces; 493 movements). In total, 79% (1344 movements) of all the alternations between surfaces involved movements to occlusal or vestibular surfaces, whereas 21% (360 movements) were to oral surfaces (tab. 18).

Table 18 Sequential analysis of the alternation frequency between tooth surfaces. Returns to the same area (diagonal) were not considered.

		Previous surface			
		vestibular	occlusal	oral	total
Following surface	vestibular	---	493	106	599
	occlusal	502	---	243	745
	oral	73	287	---	360
	total	575	780	349	1704

Alternation frequency from one area to another

A sequential analysis of the frequency distribution of the number of movements from one area to another, according to Macgregor and Rugg-Gunn [1979a], showed an accumulation of alternations from the anterior vestibular area to the left (259 movements) and right (253 movements) vestibular areas. Frequent movements from the left (329 movements) and right (280 movements) vestibular areas to the anterior vestibular area were also observed (tab. 19). In addition to the changes between anterior and posterior areas, movements from the right occlusal area to the left occlusal area (189 movements) and vice versa (166 movements) were performed frequently.

Table 19 Frequency distribution showing the number of movements of the toothbrush from one area to another according to Macgregor and Rugg-Gunn [1979a]; vest = vestibular; occl = occlusal; inc = incisal. There was no differentiation between the upper and lower jaws; non-zero values in the diagonal were caused by alternations between the upper and lower sextants of the same area and by returning to the same area after a break [Winterfeld et al., 2015] (with permission of Springer Science+Business Media).

		Area moved from									
Area		Right			Anterior			Left			total
moved to		occl	vest	oral	vest	oral	inc	occl	vest	oral	
Right	occl	95	160	32	122	74	97	166	26	6	778
	vest	157	56	16	253	15	21	12	56	2	588
	oral	38	11	7	3	70	2	9	1	11	152
Anterior	vest	50	280	3	74	29	29	56	329	3	853
	oral	89	11	76	22	21	27	57	3	77	383
	inc	142	2	2	22	13	10	127	4	5	327
Left	occl	189	18	7	65	62	113	64	83	42	643
	vest	17	49	1	259	24	22	129	46	13	560
	oral	18	3	10	8	65	6	41	11	5	167
total		795	590	154	828	373	327	661	559	164	4451

3.3.1.7 Visualisation of toothbrushing (timeline chart)

The visualisation of the brushing process produced a very heterogeneous impression. The analysis showed that 17 participants performed a sequential brushing process, 22 participants performed a systematic brushing process, and 9 participants performed both (fig. 23). Twenty-four of the participants brushed in order of jaws (first the upper, then the lower jaw, or vice versa). Seven participants brushed in order of tooth surfaces (first the oral, then the vestibular surface, or vice versa); one of these participants partly implemented the brushing technique described by Rateitschak et al. [2004] (the brushing process begins on the oral surfaces and proceeds from sextants 6 to 1; the brushing then moves to the vestibular surfaces and proceeds from sextants 1 to 6). Fifty-three participants performed unstructured brushing processes.

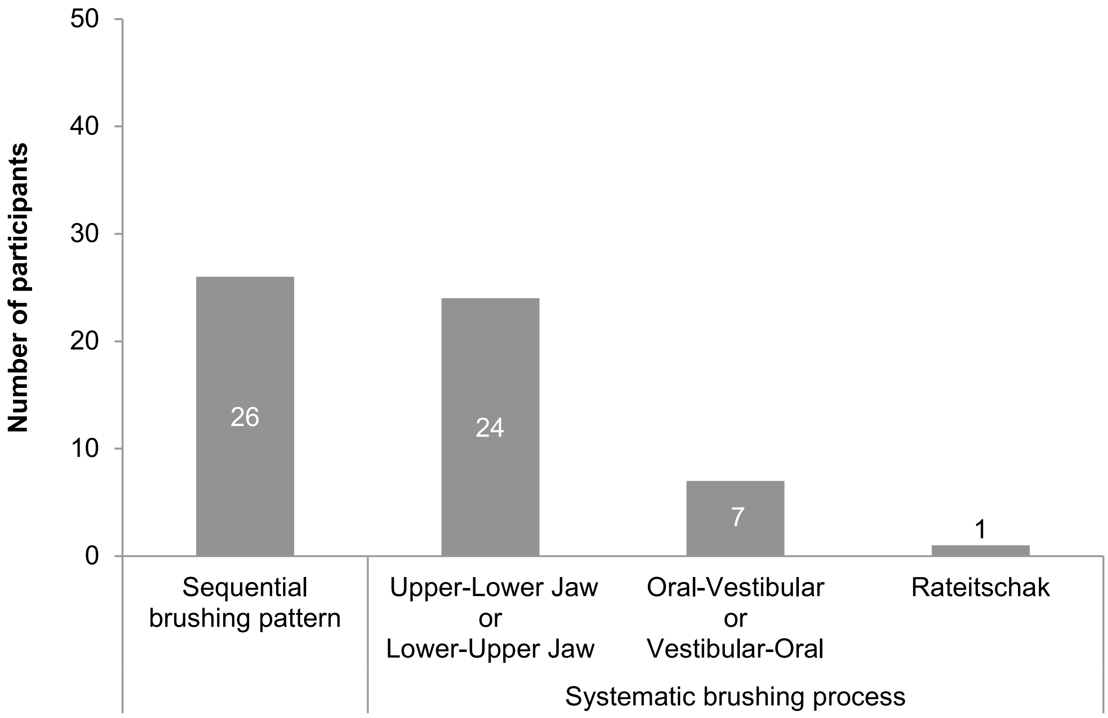


Figure 23: Analysis of motion sequences; only systematic and sequential brushing patterns are shown. Nine participants performed both systematic and sequential brushing patterns, and one participant performed oral-vestibular and Rateitschak patterns; n = 48.

3.3.1.8 Systematic and non-systematic brushing habits in relation to plaque index and effective brushing duration

A systematic toothbrushing process was performed by 31 participants, whereas 70 performed a non-systematic (sequential or unstructured) brushing process. There were no significant differences between the groups performing systematic and non-systematic brushing processes regarding the plaque scores (maximum total, mean total, mean oral, mean vestibular, mean upper jaw and mean lower jaw). The brushing duration in most areas of the mouth did not differ significantly between the systematic and non-systematic brushers, except for the oral and anterior areas (fig. 24).

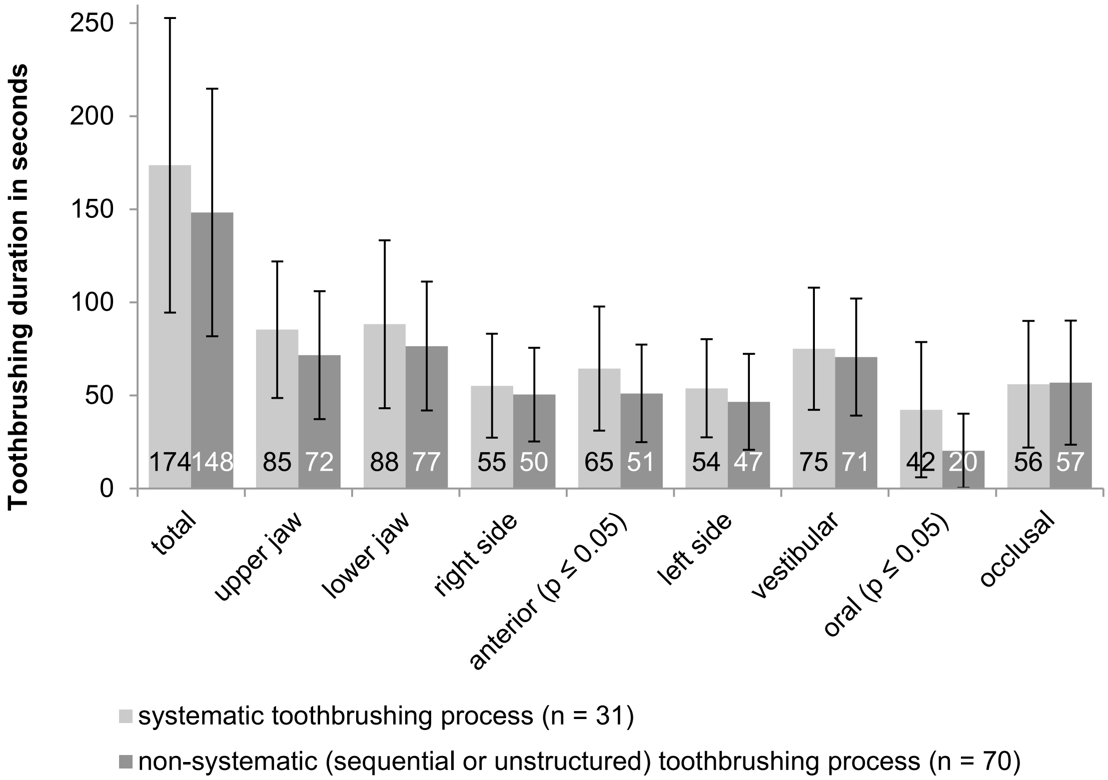


Figure 24: Toothbrushing durations in different areas stratified by systematic and non-systematic toothbrushing processes. There were significant differences between the two groups ($p \leq 0.05$) regarding the brushing duration in oral and anterior areas.

3.3.2 Flossing habits

Fewer than one-half of the participants (n = 47) flossed their teeth. In the questionnaires, only 31 of the 47 participants who practiced flossing reported using floss regularly. Differentiated analyses of the flossing habits of 5 participants, except for the usage of floss, were not possible because their flossing performance was not completely visible. Only 1 participant performed flossing with vertical movements and reached every interproximal space.

3.3.2.1 Reached sextants

More than one-half of the participants who flossed reached fewer than three sextants completely (fig. 25), and one quarter of the participants (n = 11) did not reach any sextant completely. Only 5 participants flossed all the sextants completely.

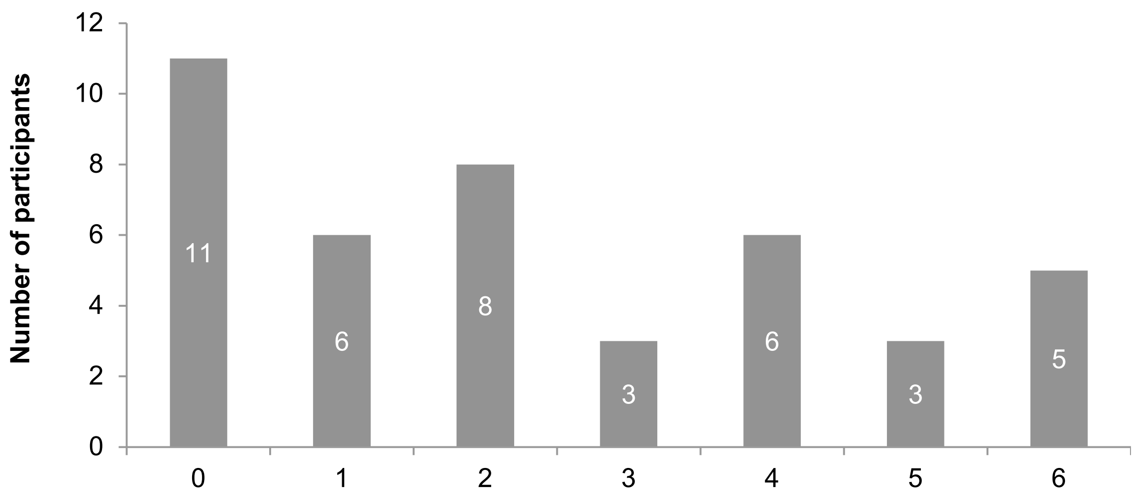


Figure 25: Sums (0 to 6) of completely flossed sextants; n = 42.

The anterior teeth in the upper jaw (sextant 2) were flossed completely more often than the posterior teeth (sextant 1 and sextant 3) (fig. 26). Fewer differences were observed between the areas in the lower jaw. The posterior teeth in the upper jaw (sextant 1 and sextant 3) were reached less frequently than the posterior teeth in the lower jaw (sextant 4 and sextant 6).

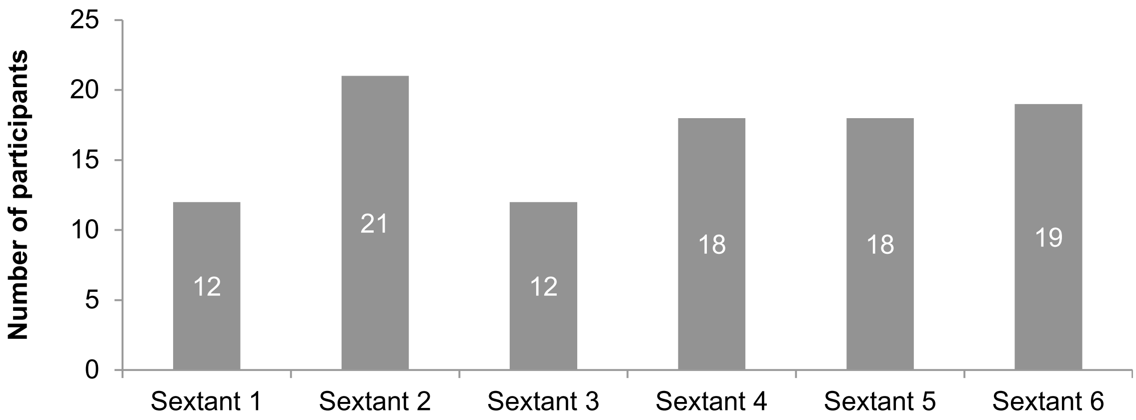


Figure 26: Completely flossed sextants (sextant 1 to sextant 6); n = 42.

The sextants that were flossed the most frequently (up to 37 times), independent of the completeness of flossing, were anterior sextants 2 (7.0 ± 3.7) and 5 (6.7 ± 5.6). The posterior sextants were flossed fewer than 8 times; sextant 1: 1.8 ± 1.7, sextant 3: 1.5 ± 1.5, sextant 4: 2.0 ± 1.5 and sextant 6: 1.9 ± 1.4.

3.3.2.2 Flossing technique

Most of participants flossed using horizontal movements (n = 22) or inserted the floss briefly into the interproximal space and removed it immediately (n = 18). Only 2 participants flossed using primarily vertical movements.

3.4 Plaque index (PI) and its relation to effective brushing duration

The mean total PI was 1.5 ± 0.4. There were no significant differences between the upper and lower jaws (1.5 ± 0.4 vs. 1.6 ± 0.4). In contrast, the vestibular tooth surfaces had considerably less plaque (1.3 ± 0.5) than the oral tooth surfaces (1.8 ± 0.3; median 1.9; minimum 0.5; maximum 2.3; $p \leq 0.001$).

In addition to the mean PI of all the teeth, the maximum PI per participant was recorded. The most common maximum PI was 3 (indicating an abundance of plaque on the tooth and gingival margin, often covering the tooth surface) (n = 65). One-third of the participants (n = 36) had a maximum PI of 2 (indicating a moderate accumulation of plaque on the tooth and gingival margin, which is visible with the naked eye), but no participants had a maximum PI of 0 or 1. The mean maximum PI was 2.6 ± 0.5.

No correlation was found between the effective brushing duration and the mean total PI (r = -0.04, n.s.; tab. 20).

Table 20 Relation between effective brushing duration and mean total PI.

Effective brushing duration	Mean total PI				Total
	0.5 to < 1	1 to < 1.5	1.5 to < 2	2 to < 2.5	
< 2 minutes	1	16	13	7	37
2 to < 3 minutes	0	20	11	5	36
≥ 3 minutes	3	9	12	4	28
Total	4	45	36	16	101

Chi-square test result: n.s.

4 DISCUSSION

The manual toothbrush is a basic tool for maintaining oral health; it is a simple, widely accepted and affordable device [Loe, 2000] that is available to most people in the world. To date, the clinical relevance for dental health of powered toothbrushes compared with manual toothbrushes remains unclear [Robinson et al., 2005], and there are no long-term data indicating the superiority of powered toothbrushes in reducing plaque and gingivitis. They also produce considerable electrical waste compared with manual toothbrushes. In a representative oral health study conducted in Germany [Micheelis and Schiffner, 2006], questionnaires revealed that 18–36% of German inhabitants between the ages of 12 and 74 years brushed with a powered toothbrush [Micheelis and Reiter, 2006]. Consequently, the manual toothbrush still plays an important role, especially in learning a brushing system and a brushing technique in group prophylaxis.

As a part of a larger study, the present work involved the analysis of videotaped oral hygiene habits in young adults. People in this age group are at the end of structured preventive programmes and should ideally perform sufficient oral hygiene. In addition to brushing duration, the type of brushing technique, a systematic approach during tooth brushing and methods of interproximal hygiene are considered relevant factors in sufficient oral hygiene and are addressed in oral hygiene education. Previously, limited information has existed about the oral hygiene habits of this group of people. The present work addresses the manual toothbrushing and flossing habits of young adults. In a first step, basic parameters such as brushing duration, types of brushing strokes and usage of floss were studied. Then, a further, in-depth analysis focused on more expanded parameters, such as patterns of movements within the dentition, including the frequency of alternations between sextants and tooth surfaces, the flossing technique and the completeness of flossing in interproximal spaces.

4.1 Study group and methods

Inhabitants of Giessen born in 1992 were examined in this study. A random sample was drawn from the data maintained by the population registration office of Giessen (Hesse, Germany). The recruitment was performed using common, standard methods (postal and by telephone) [Porst, 2001]. The response rate of 42% was in the expected range of 30–50% [Klein and Porst, 2000]. The age group was chosen on the basis that young adults, having likely received toothbrushing instructions in preventive programmes, are at the end of structured oral hygiene assistance and should have developed good oral hygiene behaviour by the age of 18 years. There was no attempt to recruit a representative sample. Nevertheless, the general characteristics of the sample conformed to the socio-demographic data and basic oral hygiene habits reported in a previous, representative, nationwide study of oral health in Germany (Vierte Deutsche Mundgesundheitsstudie; DMS IV) [Micheelis and Schiffner, 2006].

Participants with low and middle levels of formal education were less represented than participants with a high level of formal education. This problem of uneven distribution is well known [Hartmann and Schimpl-Niemanns, 1992]. However, the overall distribution of the sample's formal education level was similar to the distribution of school-leaving qualifications in the state of Hesse during the years 2010 and 2011 [Hessisches Statistisches Landesamt, 2012b].

The proportions of females (57%) and males (43%) corresponded approximately with the population data for 18- to ≤ 21-year-old inhabitants of Hesse (49% females and 51% males) [Hessisches Statistisches Landesamt, 2012a].

To facilitate a comparison between the present study and the DMS IV, we used established questionnaires to collect data on gender, formal education level, toothbrushing frequency, daily time of toothbrushing, brushing duration and brushing aids [Micheelis, 2006a]; these questionnaires were obtained from the DMS IV. We added one question about the toothbrushing technique (appendix 8.2). The DMS is a national, representative and consecutive study, currently being updated for the third time, which reports the prevalence of caries, periodontitis and related social factors. Nationwide, more than 4500 people from all social backgrounds and age groups were included in the DMS. The collected data form the basis for oral health monitoring and healthcare research in Germany. The data collected in the present study concerning socio-demographic factors, the plaque index and the use of oral hygiene aids were compared to the data of the DMS IV. The results indicated that the principle parameters of our sample corresponded very well to those of the DMS IV participants;

overall, it appears that the investigated group approximates a representative sample. For more details, see the following chapter, *4.3 Study results*.

Quality control

Observational studies are subject to the problem of being influenced by the process of observation. The participation in a study, the setting of a dental clinic and the videotaping, in particular, certainly influenced the participants. These influences were kept as minimal as possible and were identical for all the participants. All the communication processes (telephone calls, information about the study and instructions about the practical process) were standardised and trained during a one-week training period, which was monitored by an independent third party (D.H.).

During the clinical examination (assessment of the plaque index), the participants received no information about their oral hygiene conditions, with the goal of minimising any influence on their oral hygiene performance. Subsequently, the participants were accompanied (by J.I.) to an extra room, in which the toothbrushing process was videotaped. The participants were positioned in front of the mirror and were instructed to perform toothbrushing and to use the offered dental floss as in their habitual daily use. To reduce the sense of being observed by an obviously positioned video camera, the camera was installed behind a mirror and was not visible. After the participants completed the toothbrushing and flossing, the questionnaires were numbered with the participants' codes and were distributed by one investigator (J.I.), who always delivered the same instructions, stating that this was not a test and that the participants could take as much time as they needed. The participants completed the questionnaires in the same room where they had brushed their teeth, without any disturbances. When the participants had finished the questionnaires, they placed them in an envelope and gave them to an investigator (J.I. or T.W.).

The manual data transfer from the CRF to SPSS and the final data set in INTERACT were cross-checked with 100% of the data (J.I. and T.W.).

Assessment of plaque

It was not the aim of this study to examine the efficacy of toothbrushing. Because we did not assess the plaque index (PI) after brushing as an indicator of oral hygiene success, there were no attempts to standardise the participants' oral hygiene prior to the clinical examination. Nevertheless, basic data about the participants' oral hygiene status were collected to obtain an impression of the oral hygiene situation of the investigated group of subjects.

The modified plaque index of Quigley and Hein (T-QHI) [Turesky et al., 1967] is widely used because it enables a good differentiation of plaque quantity using a five-step scale. The T-QHI is easy to use and reliable, and it provides comparable results to the more complex Rustogi Modified Navy Plaque Index [Cugini et al., 2006]. The T-QHI, however, requires plaque to be stained. In the context of the present study, the staining of plaque might have caused bias because people may brush their teeth more thoroughly if they are able to see their dental plaque. Little is known about the role of visual feedback in plaque removal, although it has been shown that the impact of disclosing agents is not very strong [Tan and Wade, 1980]. However, the concrete influence of stained plaque on oral hygiene behaviour remains unclear. Therefore, the plaque index of Silness and Loe (PI) [1964] was used because it does not require the teeth to be stained. The PI appeared to be sufficient for the questions of the present study.

Coding system

For the first time, an appropriate coding system for the systematic observational measurement of continuous timed events [Yoder and Symons, 2010b] was developed for the video analysis of oral hygiene behaviour using the observation software INTERACT [Mangold, 2011]. This program is used for analyses of social interactions, primarily in the field of psychology [Hamlin et al., 2008;Vaish et al., 2009]. However, INTERACT is also suitable for many other types of video observations. The primary advantage of this program is its ability to individually program coding schemes depending on the question and variables of interest. In the present study, INTERACT enabled the registration of motion sequences with a multiplicity of chronological events and events occurring in parallel. In addition, the videos could be analysed in slow motion or could be forwarded and rewound to stop at the appropriate time point to perform coding or observe complex motion sequences. The recorded events could be analysed in a complex fashion, e.g., the frequency of alternations with the toothbrush between different areas of the mouth.

One challenge of this study was that no coding system existed to record oral hygiene habits; thus, a new coding system had to be developed. Several methods of systematic observational measurement existed, such as checklists, rating scales and count coding systems. We chose the latter because the measurement properties of count coding systems provide measures of key variables that are potentially more sensitive than those of rating scales or checklists [Yoder and Symons, 2010a].

The coding of events requires clear criteria. The selection of the variables, e.g., the division of jaws into sextants, was based on studies conducted by Macgregor and Rugg-Gunn [Rugg-Gunn and Macgregor, 1978;Macgregor and Rugg-Gunn, 1979a], who have published the most detailed and methodically unsurpassed studies on oral hygiene behaviour from the seventies until today. During the first viewing of the videos, the heterogeneity of the motion sequences performed by the participants became obvious. The coding criteria were defined as the result of a lengthy group discussion and development process. First, two investigators (J.I. and T.W.) developed coding systems in INTERACT for toothbrushing behaviour and flossing behaviour. Several videos were analysed using these codes, which allowed the detection of inaccuracies in the definitions of several variables, such as *flossed sextant* and *brushed sextant* (e.g., overlapping two sextants with the toothbrush head). The definitions were refined three times in the same way to allow every observed event to be coded. The final result was a coding scheme of mutually exclusive (only one code can be associated with a particular event) and exhaustive codes (there is a code for every event) [Bakeman and Gottman, 1997a] for continuous behaviour sampling (event and timed-event sampling) [Yoder and Symons, 2010b].

A total of 37 codes were used to analyse one video. This process was not possible by viewing the video only one time. It became clear that the division of codes into four rounds of coding was more suitable for analysing a video. The first pass of coding was created to determine the beginning and ending of the brushing process. The second pass coded the areas reached by the toothbrush, and the third pass coded the brushing strokes that were used. A fourth pass of coding was performed if the participant had flossed.

Reactivity

Because this study used videotaping to investigate everyday toothbrushing and flossing habits, the awareness of being filmed might have influenced the behaviour of the participants. Several studies have investigated the hypothesis of reactivity, meaning that participants may act differently when watched than when not. These studies concluded that almost all the examined variables showed no differences [Yoder and Symons, 2010b]; however, these variables were not specifically related to dental research. Regarding the observation of oral hygiene behaviour, one study demonstrated minor differences in brushing duration, albeit only in specific areas of the mouth, between participants who knew that they were being filmed and those who were unaware of being filmed [Macgregor and Rugg-Gunn, 1986]. The only significant differences were observed for brushing mandibular areas. Those who knew they were being filmed spent less time brushing posterior buccal areas (38% of mandibular brushing duration) and more time brushing the occlusal (28%) and lingual (9%) areas of the mandibular arch compared with those who were unaware of being filmed (44%, 24% and 7%, respectively). Despite these small differences, which were limited to specific areas of the mouth, the total brushing duration and the brushing duration at all the maxillary areas were not found to be influenced by video observation. Overall, only a minimal influence of observation on brushing duration in specific areas of the mouth can be assumed. Mierau et al. [1989] investigated habitual patterns of manual toothbrushing among 85 students aged 23 ± 1.4 years during 9 observation sessions performed within 3 days. Their results revealed only small intraindividual variations in brushing technique, sequence, duration and changes between areas of the mouth. Another study showed a perfect reproduction of brushing habits by ten participants who repeated their brushing sequence twice, indicating stable brushing patterns that were not influenced by spontaneous modifications [Ganss et al., 2009]. These aspects must be considered in the interpretation of the present data. The examined parameters of toothbrushing performance appear to represent a stable, habitual behaviour that is not easy to influence. Nevertheless, the participants potentially brushed more thoroughly than they did at home.

4.2 Examiner calibration and agreement

Plaque index (PI) according to Silness and Loe

To ensure the reliability of the recording of the PI scores, the clinical examiner (T.W.) was calibrated against an experienced reference examiner (N.S.). The calibration employed 16 volunteers who were not involved in the study. To prevent assessment drift, the calibration was performed three times: (I) before the study began, (II) after 33 study participants had been examined and (III) after 66 study participants had been examined. According to the classification of Landis and Koch [1977], the agreement between the examiners was almost perfect (I = 0.90; II = 0.82; III = 0.95).

Video coding

To ensure that the procedures were replicable [Bakeman and Gottman, 1997b], all the videos were analysed by another observer (J.I.). The observers analysed the videos independently at two different institutes (Dent-GI and Psych-MR) within a period of 4 months. Additionally, the investigator (T.W.) whose data are presented here coded 10% of a randomly selected group of videos before and after the entire analysis to calculate the intrarater agreement.

The determination of the intra- and interrater agreement for the video analysis was performed with INTERACT because this program offers the option of calculating the kappa coefficient using an algorithm for timed-event sequential data [Bakeman et al., 2009]. Instead of the 'traditional' Cohen's kappa [Cohen, 1960], we used a modification of it called 'event-based kappa for timed-event sequential data', which is implemented in INTERACT [Bakeman et al., 2009]. Time was considered as events were aligned, resulting in a *timed-event alignment kappa* [Bakeman and Quera, 2011a]. Two tolerances could be set: overlapping [%] and start tolerance [fps/s], which are for events with duration and selectively occurring events, respectively. In the present study, the overlapping tolerance for events with duration was set to 85%, and the start tolerance was set to 24 frames per second (fps) = 0.96 seconds. The standard setting in INTERACT is 50% overlapping time; however, the INTERACT help file recommends a lower percentage for codes that are shorter than 2 seconds to obtain a better interrater agreement [Mangold, 2009]. Most of codes within the data set were short, but by definition, they were longer than one second. To ensure higher-quality data, more stringent requirements for agreement were chosen, including an overlapping tolerance of 85%. A start tolerance of 24 fps = 0.96 seconds was set because the shortest coded event was one second or longer by definition, which made a tolerance higher than the shortest event not meaningful. For events without duration, a start tolerance of 2 seconds was set, which was important for the flossing codes. Whenever an interproximal space was reached by the floss, an event was coded. However, the exact time at which the event was coded – at the beginning or shortly thereafter – was not important because only a point in time, not the duration, was registered. A tolerance of less than 2 seconds distorted the real agreement. A tolerance longer than 2 seconds was not appropriate because the next event could occur in the meantime.

The intrarater agreement for classes before the video analysis began was almost perfect (κ = 0.89–1) and for codes between 66.7–100%. The intrarater agreement for classes after the analysis had been completed was again almost perfect (κ = 0.86–1) and for codes between 73–100%, indicating the absence of drift during the video analysis.

The interrater agreement for all the classes ranged from moderate (κ = 0.45) to almost perfect (κ = 1). However, there was a distinct discrepancy in the variable *jiggling* (agreement = 0%). A further analysis of the interrater agreement revealed that only one investigator (T.W.) had coded the variable *jiggling* while the other investigator (J.I.) coded *horizontal-linear*; thus, a systematic error was obvious. To resolve this discrepancy, the variable *jiggling* was transformed into *horizontal-linear* for all the data. One reason for the low agreement might be the similarity between the two horizontal movements. Both movements are horizontal strokes to a greater or lesser extent: during brushing with a jiggling stroke, the bristles of the toothbrush head remain in place, whereas they do not remain in place during brushing with a horizontal-linear stroke. Another reason could be associated with the video recording itself: there was a question regarding whether the resolution of the video allowed the toothbrush's bristles to be displayed in sufficient detail. If the presented codes are used in future studies, it will be important to consider how the coding of the variable *jiggling* should be trained.

The interrater agreement for the variable *unspecific* of the class *brushing stroke* was only slight (agreement = 14.5–29%). One reason could be that there was no explicit definition of unspecific brushing strokes, except for non-appropriate brushing strokes. Therefore, every brushing stroke that could not be assigned to a defined variable was coded as *unspecific*. Nonetheless, most of the brushing strokes were clearly assignable to a code, which led to the coding of very few unspecifc strokes, which also may have resulted in a low kappa coefficient.

Bakeman and Quera [2011d] investigated factors affecting kappa values; the two most important factors were found to be observer accuracy and the number of codes. *'For example, […] with five codes, if you want observers who are at least 85 percent accurate, you should require kappas of about 0.65.'* [Bakeman and Quera, 2011c]. The implications for the present method are as follows: We performed four passes of coding, with each containing between 2 and 17 possible codes. As an example, our coding class *brushing strokes* had 5 codes, and the interrater agreement was κ = 0.67. This kappa value initially appears not as high compared with the classification of Landis and Koch [1977], although it is still substantial. However, according to the definition of Bakeman and Quera [2011c], this kappa value corresponds to an observer accuracy greater than 85%. Considering that an observer accuracy of at least 80% is acceptable [Bakeman and Quera, 2011b], our kappa value of 0.67 is quite good.

The method of video analysis used in the present study appears to be very robust. The good intra- and interrater agreement values between a dentist (T.W.) and an individual outside the dental field (J.I.) indicate the universality and robustness of the coding scheme. Although several variables required more training than the others, the data demonstrate the high reproducibility of the method.

4.3 Study results

4.3.1 Questionnaires

Oral hygiene education

It was assumed that our study group had participated in oral hygiene education. Since 2004/2005, every school year, the German working group for the dental care of youth (Deutsche Arbeitsgemeinschaft für Jugendzahnpflege e.V.; DAJ) has collected data concerning the numbers of children and adolescents who were reached by group prophylaxis measures in kindergartens and primary schools. Participation in the first wave of group prophylaxis programmes in Hesse during the years 2004/2005–2011/2012 ranged from 63–80% in kindergartens and from 71–84% in primary schools [Goepel and Bertzen, 2008;Goepel and Bertzen, 2009;DAJ, 2013a;DAJ, 2013b;DAJ, 2013c;DAJ, 2013d;DAJ, 2013e;DAJ, 2013f]. Thus, the majority of children educated at public institutions were reached by group prophylaxis. The data regarding individual prophylaxis appear different. The overall utilisation of individual prophylaxis by eligible individuals increased between 1993 (9%) and 2003 (40%) [Gesundheitsberichterstattung (GBE) des Bundes, 2013]. However, the interest in individual prophylaxis was strongly age-related: it decreased beginning at the age of 19 years [Schneller et al., 2001].

In the present study, most of the participants (n = 82) reported that they had received education in toothbrushing. Ninety-six percent of the participants who had received toothbrushing education (n = 79) were instructed in school or kindergarten by a dentist, and 4% (n = 3) were instructed by their parents only. Because we know nothing about the regional origins of the participants and the proportion of their lives that had been spent in Hesse, conclusions regarding participation in preventive programmes in Hesse must formed with caution. Nevertheless, 82% of the participants had previously received some instruction in toothbrushing. Thus, the basic assumption that the data of the group under study comply with the data of implemented preventive programmes is confirmed.

Frequency and daily time of toothbrushing

Alfred C. Fones explained in 1921 that *'[s]ome dentists advise their patients to brush their teeth before retiring; some, night and morning[…]'* [Fones, 1921]. He recommended brushing the teeth after each meal, four times per day. More than thirty years later, Charles C. Bass [1948;1954] conducted studies examining the formation of dental plaque, the development of caries and the prevention of tooth decay by personal oral hygiene. He suggested a brushing frequency of twice per day: before going to bed and before breakfast.

The current recommendation concerning the frequency of toothbrushing is to brush twice per day [Davies et al., 2003;Claydon, 2008;Muller-Bolla et al., 2011;American Dental Association, 2013]. It has been shown that plaque reduction increased with toothbrushing twice per day or more often [McKendrick et al., 1970] and that gingival health also improved with toothbrushing up to twice per day [Claydon, 2008]. Nonetheless, nothing is known about how often plaque must be removed to prevent the development of dental diseases [Van der Weijden and Slot, 2011]. In principle, meticulous toothbrushing once per day is sufficient to maintain oral health [Attin and Hornecker, 2005], but it has been argued that patients should brush twice per day because they are unable to clean their teeth sufficiently by brushing only once [De la Rosa et al., 1979].

A second reason for brushing twice per day that is also important is the regular daily application of fluorides. The use of fluoride toothpaste is efficacious in reducing dental caries in children and adolescents compared with non-fluoride toothpaste [Marinho et al., 2003]. However, it should also be noted that poor oral hygiene cannot be compensated by the intensive use of fluorides [Nyvad, 2008].

In 1971, German students (n = 2246) were asked about their oral hygiene behaviour [Gülzow H.-J. and Keilwerth, 1971]. Eleven percent of the students reported brushing their teeth never or occasionally; nevertheless, 69% reported brushing more than once per day. It was shown that the frequency of brushing twice daily in Germany increased over time (1997–2005), from 61–74% [Staehle, 2004] to over 80% [Micheelis and Schiffner, 2006;HBSC-Team Deutschland, 2012]. In a study of toothbrushing frequency in European countries, Germany ranked in the top five [Currie et al., 2013]. The present results show that 84% of the participants reported brushing their teeth twice per day or more often. Nevertheless, 16% of the participants did not comply with this recommendation.

In addition to frequency, the time of day when toothbrushing is performed appears to be relevant, although there is insufficient evidence on which to base recommendations. A closer look at the present results concerning daily toothbrushing shows that two-thirds of the participants brushed their teeth twice per day: after waking up/before breakfast or after breakfast and before going to bed. From a biological point of view, brushing the teeth after each meal is plausible to avoid the retention of cariogenic food over a longer period [Bass, 1954]. In a German study examining preventive programmes in dental practices, 457 dentists provided information about their recommendations regarding the time of day when toothbrushing should be performed: 65% of them suggested brushing after each meal, and 57% recommended brushing in the evening [Bieniek et al., 1990]. Despite these recommendations, the question about the 'proper' daytime cannot be answered due to the lack of controlled studies. Regarding the prevention of dental disease, *'[…] there is no evidence to indicate the relative anti-caries benefits of brushing before or after eating meals.'* [Davies et al., 2003]. The recommendation with respect to fluoridation is to *'[…] brush last thing at night and on one other occasion'* because *'[…] brushing before going to bed with a fluoride toothpaste should take place just prior to going to bed […]'* [Davies et al., 2003]. Regarding the prevention of periodontal diseases, there is a lack of scientifically sound literature about toothbrushing before or after meals.

In addition to the biological aspects of these recommendations, behavioural aspects of the ritualisation of toothbrushing play a role regarding the forming of a habit to clean the teeth regularly [Hornecker et al., 2003].

<u>Oral hygiene aids and behaviour</u>

When we ask our patients about toothbrushing, almost everyone who cleans their teeth reports brushing with a toothbrush and toothpaste. However, additional oral hygiene aids exist, and the most important are designed for cleaning the interproximal tooth surfaces.

A comparison of this study and the results of the DMS IV for 15-year-old participants [Micheelis and Reiter, 2006] revealed similar trends regarding the use of oral hygiene aids: Virtually all the participants used a toothbrush (manual or powered) and toothpaste. Mouthwash was used by 22.1% of the participants in the DMS IV and 34.7% in the present study, sugar-free chewing gum by 39.6% (DMS IV) and 31.7% (present study), toothpicks by 13.1% (DMS IV) and 21.8% (present study), interproximal brushes by 8.4 (DMS IV) and 5.0% (present study) and floss by 22.5%

(DMS IV) and 36.6% (present study). Overall, only approximately one-third of the participants in both studies used oral hygiene aids for interproximal cleaning in addition to toothbrushes. These data indicate that cleaning the interproximal tooth surfaces is being neglected.

The enquiry of the oral hygiene habits looms large regarding the prevention of caries and periodontitis [Hellwig et al., 2006]. Therefore, an index for oral hygiene behaviour was established by the DMS I [Bauch et al., 1991]. This index classifies oral hygiene into ‘good’ and ‘bad’ levels based on three important oral hygiene variables assessed by questionnaires. The following criteria must be fulfilled for a good oral hygiene level: toothbrushing must be performed (I) at least twice per day and (II) ‘after a meal’ or ‘before going to bed’, and (III) the brushing duration must be at least 1.5 minutes. In the course of the DMS III [Micheelis and Schroeder, 1999], the index was modified regarding one criterion: the brushing duration was changed from 1.5 to 2 minutes. These criteria were also used by the DMS IV [Micheelis, 2006b]. All participants who did not fulfil the aforementioned criteria were classified as having a bad level of oral hygiene. This approach is arbitrary, and there is no proof of its clinical relevance to date.

To compare the DMS IV and the data of the present study, we also classified the oral hygiene level according to the index of the DMS IV [Micheelis, 2006b]. The oral hygiene level in Germany improved from 1997 to 2005 [Micheelis and Reiter, 2006]. In 1997, 28% of participants aged 12 years had good oral hygiene, and 73% had bad oral hygiene. In the 2005 study of participants aged 12 and 15 years, approximately 41% had good oral hygiene, and approximately 59% had bad oral hygiene. A similar trend was detected in individuals 35-44 and 65-74 years of age [Micheelis and Reiter, 2006]. Similar results concerning the oral hygiene level were observed in the present study: 37% of the participants had a good oral hygiene level, and 58% had a bad oral hygiene level (5% provided no information).

There is scant literature regarding all the variables addressed by the questionnaires. However, the characteristics of the answers about oral hygiene aids and the oral hygiene behaviour of the participants in the present study correspond to the examined group of the DMS IV, indicating that our study group was valid.

4.3.2 Video analysis

4.3.2.1 Toothbrushing

Toothbrushing duration

An important indicator of a sufficient oral hygiene level is brushing duration [van der Weijden et al., 1993;Micheelis and Schiffner, 2006;Gallagher et al., 2009;Slot et al., 2012]. It has been shown that brushing duration was consistently correlated with plaque removal [Honkala et al., 1986], but the recommended brushing duration has varied over the course of history and remains controversial. There is no doubt that a minimum amount of time is necessary to brush every tooth and its surface, and the brushing duration should be considered a result of the individual brushing performance.

An early German study of the efficacy of toothbrushing methods and toothbrushing aids, which investigated 20 dental students, showed that 25% of tooth surfaces remained coated with plaque after a brushing duration of approximately 3 minutes [Gülzow H.-J. and Busse G., 1970]. The authors concluded that a brushing duration of at least 4 to 5 minutes was required to clean the tooth surfaces in an optimal way. However, it has been shown that plaque removal is not linearly related to brushing duration. To investigate whether a correlation exists between brushing duration and plaque removal, Gallagher et al. [2009] examined 40 untutored participants (18-63 years old). The results showed that as the brushing duration increased, the plaque removal increased for a period of 0.5 to 3 minutes, and the amount of plaque removed was highly dependent on brushing duration at shorter times, but not at longer times. The authors concluded that a hyperbolic relationship exists between brushing duration and plaque removal, with the highest increase in efficacy at a total brushing time of up to two minutes. Another study investigating plaque removal in relation to brushing duration using four different toothbrushes (one manual and three powered) also showed that the main effect on plaque reduction was reached after each quadrant had been brushed for 30 seconds [van der Weijden et al., 1993], equivalent to a total brushing duration of two minutes. This finding was reflected by a subanalysis of a systematic review that showed a stronger effect on plaque removal after two minutes of brushing (41% mean plaque reduction) compared with one minute (27% mean plaque reduction) [Slot et al., 2012]. Overall, it appears that plaque removal reaches a plateau after 2 minutes of toothbrushing.

In the present study, the mean brushing duration of the participants was considerably longer than 2 minutes, which is within the range of international recommendations [Gallagher et al., 2009;dos Santos et al., 2011;Muller-Bolla et al., 2011;Sandstrom et al., 2011]. Only 8 participants brushed for less than 1.5 minutes. The brushing duration in the present study was distinctly longer than the values of earlier observational studies, in which individuals with a mean age of 22 years brushed for a mean duration of approximately 1 minute [Robinson, 1946], young adults (mean: 19 years; minimum: 17; maximum: 34) brushed 1 minute [Dahl and Muhler, 1955], adolescents aged 18-22 years brushed less than 1 minute [Rugg-Gunn and Macgregor, 1978;Macgregor and Rugg-Gunn, 1984;Macgregor and Rugg-Gunn, 1985], and adults brushed less than 2 minutes [Ganss et al., 2009]. A recent study of toothbrushing behaviour among 6- to 12-year-olds found a brushing duration of 1.8 ± 1 minutes, and 36% of the participants brushed longer than 2 minutes [Sandstrom et al., 2011]. Based on these studies, it can be concluded that there has been a tendency for brushing duration to increase over the last five decades.

However, brushing duration provides no information about the completeness of reaching all teeth or how thoroughly the participants cared for the different areas of the mouth. The present results represent an impressive demonstration of the exact events that occur during a brushing performance. The brushing durations differed minimally between the upper and lower jaws, as well as between the left, right and anterior surfaces. However, the oral surfaces were brushed for a considerably shorter time than the vestibular surfaces. Only approximately 17.4% of the effective brushing duration occurred at the oral surfaces, whereas 46.2% of the effective brushing duration occurred at the vestibular surfaces. Strikingly, these results are comparable to those of Rugg-Gunn and Macgregor [1978], who found that young adults (aged 18-22 years) brushed for equally long times on the upper and lower jaws as well as on the left, right and anterior tooth surfaces, whereas only 10% of the brushing duration occurred at the oral surfaces, and 60% of the brushing duration occurred at the vestibular surfaces. In 1946, an observational study found that *'[…]brushing was almost entirely confined to labial (and buccal) regions'* [Robinson]. Therefore, it appears that emphasising brushing the vestibular surfaces while neglecting the oral areas is a phenomenon that transcends time, education and culture.

In additional to the uneven distribution of brushing time at the vestibular and oral tooth surfaces, our participants spent approximately one-third of the brushing duration (36.3%) on the occlusal surfaces. However, brushing these surfaces appears to not be as important as brushing the smooth surfaces of the teeth. The plaque scores on the occlusal tooth surfaces differ to a lesser extent than those on the smooth surfaces when toothbrushing is omitted for several days [Ekstrand et al., 1993]. This finding is due to the teeth in full occlusal function being subject to mechanical wear, which limits plaque accumulation on the occlusal surfaces [Carvalho et al., 1989;Carvalho et al., 1991;Carvalho et al., 1992]. An exception are the erupting primary or permanent molars and premolars because their occlusal surfaces have a reduced mechanical function and accumulate large amounts of plaque [Carvalho et al., 1998]. The amount of time spent brushing occlusal surfaces, our participants showed, should be redistributed in favour of the oral surfaces.

The question of the correct brushing duration remains unanswered. We dentists try to educate our patients to clean every tooth surface. To achieve this goal, a minimum of time must be invested. We know that extending the brushing duration results in more plaque removal, up to a certain point [Gallagher et al., 2009]. This finding might be explained by assuming that people settle into routine brushing patterns rather than brushing areas they have likely never reached before. Thus, the first recommendation for improving oral hygiene should be to use a brushing system to reach every tooth surface. Another idea is to occasionally alter the brushing pattern that is usually performed [Canadian Dental Association, 2013]. The individual brushing pattern implies an individual brushing duration for each person depending on different parameters, such as number of teeth, tooth malposition, manual ability and the use of additional oral hygiene aids.

In addition to observational studies of toothbrushing behaviour, a number of studies have investigated brushing duration using questionnaires. An earlier study revealed that people did not evaluate themselves accurately. The participants in that study estimated their brushing duration to be approximately 2-3 minutes, whereas their performed brushing duration was only 1 minute [Saxer et al., 1998]. In the present study, however, there was a good correlation between the observed total brushing duration and the reported brushing duration of the participants ($r = 0.43$; $p \leq 0.01$). Because most of the participants in the present study brushed longer than 2 minutes and most reported a brushing duration in the range of their observed brushing performance, it can be assumed that the official recommendations concerning brushing duration had been not only theoretically but also physically implemented.

Starting location

With respect to the starting location and the subsequent brushing process, a question is raised concerning whether a natural behaviour with preferred motion sequences exists. For example, it could be assumed that easily accessible and visible areas or areas on the side contralateral to the dominant hand were brushed first. Actually, the vestibular tooth surfaces, especially those of the anterior teeth, appear to be the preferred starting location [Gülzow H.-J. and Busse G., 1970;Galinsky et al., 1975;Macgregor and Rugg-Gunn, 1979a;Kleber et al., 1981]. Detailed observations of children and adolescents have also shown that half of the participants began brushing on the anterior vestibular surfaces, and another 25% began on the left vestibular surfaces [Macgregor and Rugg-Gunn, 1979a]. The present results differ from those observations. Only 18% of the participants started brushing on the anterior vestibular surfaces, 30% on the posterior vestibular surfaces and only 3% on the oral surfaces. The other half of the participants started brushing on the occlusal surfaces. A reason for this discrepancy might be that the oral hygiene education in Germany comprises the teaching of the KAI brushing system, which focuses on cleaning the occlusal tooth surfaces first.

Toothbrushing instructions for children take up preferred behavioural patterns, and chewing on the toothbrush leads children to start brushing on occlusal surfaces when applying the KAI brushing system. However, a question arises regarding whether teaching the KAI system leads to a preference for brushing the occlusal surfaces and underestimating the importance of brushing the oral surfaces. Perhaps this system should be modified at an early age to create an individual sufficient brushing technique, depending on the individual's maturity level and ability.

Brushing events

Although the participants reached all the sextants, a more detailed analysis that considered the tooth surfaces revealed differences. Only half of the participants brushed the oral surfaces of the upper jaw, and nearly one-third brushed the oral surfaces of the lower jaw. Only 26% of the participants brushed all twelve areas (the oral and vestibular areas of all the sextants). Participants in earlier studies also exhibited deficiencies in the cleaning of the oral tooth surfaces [Macgregor and Rugg-Gunn, 1979a;Kleber et al., 1981;Macgregor and Rugg-Gunn, 1984].

Subsequent to the start of brushing, the toothbrushing process was characterised by very frequent alternations between the areas of the mouth. When performing a systematic toothbrushing procedure, every section should be brushed once, for a total of 18 brushing events (6 sextants x 3 surfaces = 18) over the complete course of toothbrushing. In contrast, a mean of 45 brushing events were observed during a mean effective brushing duration of approximately 2.5 minutes. Considering that most participants did not reach every area, it is obvious that the tendency to remain at one location was limited; rather, the participants preferred a certain dynamic.

The changes in location were not random but followed specific patterns. Initially, the participants alternated to the left, anterior and right sides. Interestingly, this motion sequence was also observed in an earlier study [Macgregor and Rugg-Gunn, 1979a], indicating that it may be a prevalent spontaneous behaviour. The present analysis also showed that these alternations occurred less frequently between the upper and lower jaws; instead, they were restricted to a single dental arch. The most common alternations in the upper jaw involved movements to the neighbouring sextants, and those in the lower jaw occurred between the left and right sides without the anterior area being touched. In contrast to earlier results showing a preference for brushing the left rather than the right side after brushing the anterior [Macgregor and Rugg-Gunn, 1979a], the present study showed that the toothbrush was moved equally frequently to the left or right side in both jaws after the anterior area was brushed. Changes between the upper and lower jaws occurred most frequently on the right side.

A sequential analysis of the present data concerning the alternation frequency between tooth surfaces showed that the most common movement changes occurred from the vestibular and oral surfaces to the occlusal surfaces. This result corresponds to the results of Macgregor and Rugg-Gunn [1979a]. There was a tendency to most frequently perform changes from the vestibular, oral and occlusal tooth surfaces to the occlusal and vestibular surfaces (79% of all alternations between surfaces), whereas only approximately one-fifth (21%) of alternations involved movement to the oral surfaces. On the one hand, the oral areas are anatomically more difficult to reach regardless of the brushing technique used [Gülzow H.-J. and Busse G., 1970]. On the other hand, different ranges of visual and sensory perception could play a role for neglecting oral surfaces.

A closer inspection of the alternation frequencies between areas revealed results that correspond closely to the findings of Macgregor and Rugg-Gunn [1979a]. A high frequency of alternations was found for three different brushing sequences (the values of the alternation frequency were converted to percentage regarding the total frequency of alternations of the origin area):

(I) From the anterior vestibular area to the left (31% present study; 41% Macgregor) and right (31% present study; 29% Macgregor) vestibular areas;

(II) From the left (59% present study; 52% Macgregor) and right (47% present study; 50% Macgregor) vestibular areas to the anterior vestibular area;

(III) From the left occlusal area (25% present study; 36% Macgregor) to the right occlusal area, and vice versa (24% present study; 29% Macgregor).

It appears that these brushing sequences represent movement patterns that are unconsciously anchored in the habitual brushing behaviour of adolescents, independent of educational or socio-demographic background. This finding raises questions concerning the reasons for such behaviour. One explanatory approach could involve the child's physiologic development and oral hygiene education. Another explanation could involve the physiology of the brain and the related functional aspects of motor coordination. During mastication, frequent and rhythmic movements of tongue, lips, jaws and cheeks occur. It has been shown that sensory feedback from the orofacial system modifies the proper coordination of oral structures [Sessle, 2006]. For example, the control of mastication is largely dependent on sensory feedback, particularly from intraoral mechanoreceptors [Lund, 1991]. The neural control centres for chewing and swallowing are located in the brain stem and the cerebellum. The latter may be involved in coordinating the timing of glossomandibular movements according to variations in the position and shape of food boluses and the need to swallow [Quintero et al., 2013]. We hypothesised that the presence of a solid body, i.e., a toothbrush, could trigger such sensory feedback from intraoral, joint, and muscle receptors similar to the feedback triggered by food [Lund, 1991], resulting in a muscular reaction, which could influence the position of the toothbrush. It was also shown that the functional organisation of the cerebellum involves a close relationship between the active zones that are responsible for hand and facial movements [Grodd et al., 2001]. Tongue movement-related neuronal activations have been shown to overlap with the finger movement-related activation of parts of the dentate nucleus, the largest nucleus in the cerebellum [Dimitrova et al., 2006]. The '*[…]high level of overlap between functionally connected body segments (hand-foot, hand-face/mouth) in the cerebellum might favour the production of adaptable motor synergies while minimizing the need for information transfer and neural connectivity.*' [Mottolese et al., 2013]. This contiguous local relationship between the control centres that are responsible for facial and hand movements lead to the theory that toothbrushing is based on close interactions among oral, facial and hand muscles, which are under the continuous control of orofacial sensory feedback. This may be a triggering factor for frequent alternations of the toothbrush between different areas of the mouth.

The anterior area receives more attention during toothbrushing than the other areas in terms of repeated returns to this area. In addition, the brushing duration and frequency values were slightly higher in the anterior area. Considering that the anterior deciduous teeth are the first to erupt in children, initial attempts at toothbrushing could be performed in this area by children and their parents. As more teeth erupt, more areas are (or should be) included in the brushing process, which could lead to the observed repetitive returning to anterior areas. A second theory is based on the anterior teeth (at least their vestibular surfaces) being easier to reach than the other teeth, which may lead to the development of a preference for brushing the anterior teeth. Finally, the anterior teeth are the most visible area during actions such as speaking, smiling and eating. Many people brush their teeth precisely because of this aesthetic focus [Macgregor et al., 1997].

Brushing strokes

'Brushing strokes' is the generic term for different types of brushing movements performed with a toothbrush. A brushing movement is oriented towards three axes in space and can be described horizontally and vertically regarding the occlusal plane. A toothbrushing technique includes these movements either singly or in combination, resulting in the performance of circular or alternating movement patterns. For example, the Bass technique [Bass, 1954] focuses on jiggling (short horizontal) movements at the gingival margin of the tooth, which alternate with vertical wiping movements to the tooth's crown on the vestibular and oral surfaces of all the teeth. The occlusal surfaces are brushed with horizontal movements. Similar movements are used when performing the modified Stillman technique: vibratory (slight rotary) movements are performed at the gingival margin and the cervical part of the tooth surface, and a vertical-roll movement is performed in the occlusal direction [Van der Weijden et al., 2008]. Another toothbrushing technique, the Fones technique, focuses on simultaneously brushing the vestibular surfaces of the teeth of both closed jaws using circular movements. The oral and occlusal surfaces of the posterior teeth are brushed horizontally, and the oral surfaces of the anterior teeth are brushed vertically [Fones, 1921]. There are many other toothbrushing techniques, and they all have the same aims: reducing dental plaque and saving the surrounding tissues.

Although there is a consensus about keeping a brushing system for reaching every tooth and all of its surfaces, there exists a lack of clarity about brushing techniques [Muller-Bolla et al., 2011;dos Santos et al., 2011]. For example, horizontal brushing strokes are considered an aetiological factor for gingival recessions [Rajapakse et al., 2007] or cervical tooth wear [Bartlett and Shah, 2006]. Various results have been published regarding the effectiveness of different brushing techniques for plaque removal, and international specialised societies of different countries have provided various recommendations [Muller-Bolla et al., 2011].

Published observational data concerning the most frequently used brushing strokes are also highly heterogeneous. Rugg-Gunn and Macgregor [1978] observed that the vestibular and oral surfaces of the posterior teeth were primarily brushed with horizontal or vertical strokes, and the anterior area with vertical strokes; however, circular strokes were rarely observed. Children between 8 and 12 years of age primarily exhibited horizontal brushing movements [Sharma et al., 2012], whereas middle-aged adults mainly brushed with circular strokes [Ganss et al., 2009]. Nevertheless, it is remarkable that different types of brushing movements are disproportionately common in specific areas of the mouth. The reason for this finding could be variations in the accessibility of areas to the toothbrush, but it is unclear which factors determine the type of movement.

In the present analysis, the main brushing movements on the vestibular surfaces were horizontal and circular strokes, and those on the oral surfaces were horizontal and vertical strokes.

In view of the variety of defined brushing techniques, the question arises whether such fixed systematic movements are implemented. The brushing movements of the present participants, however, were highly heterogeneous. An exception was the Fones technique, which is characterised by circular brushing strokes with the toothbrush simultaneously contacting the teeth of both closed jaws [Fones, 1921] and is easy to identify. Elements of the Fones technique were performed by 78% of the participants; moreover, they constituted at least 30% of the total brushing duration of one-third of the participants. These elements (large circular movements on both closed jaws) are taught in group prophylaxis from kindergarten through the first and second grades of primary school. The observed high prevalence of elements of the Fones technique in our group supports the assumption that brushing patterns originate in childhood. The Fones technique is the first step towards the development of an elaborated brushing technique, which should begin in the third grade of primary school: smaller circular movements should be performed separately on every vestibular surface with the jaws opened [Landesarbeitsgemeinschaft für Jugendzahnpflege (LAGH), 2012]. Therefore, it must be considered that many of the participants had not further developed their brushing movements or technique since childhood.

One of the most frequently recommended toothbrushing techniques for adults in the literature and, e.g., on the websites of many dentists, is the modified Bass technique:

'*In brushing the buccal, labial, and lingual surfaces the bristles should be forced directly into the gingival cervices and into the sulci between the teeth, at about a 45 degree angle to the long way of the teeth. With the bristles forced into the cervices as far as possible, short back and forth movements of the brush dislodge all soft material which they reach on the tooth within the crevice.'* [Bass, 1954]. The modification is an additional rolling brushing stroke parallel to the long tooth's axis from cervical to coronal (termed a '*vertical-roll*' in the present study). Only one participant performed a combination of alternating horizontal and vertical brushing movements in the style of the modified Bass technique. It has been shown that this technique is difficult to learn [Schlueter et al., 2010], and performing this technique has no effect on achieving lower plaque scores [Schlueter et al., 2013]. The present results indicate that 99% of the participants did not perform the modified Bass technique, even in a basic form; thus, it could be very difficult for them to learn this technique. The question arises whether it is meaningful to re-educate such a group of people. There is a great need for new studies to investigate how existing brushing patterns could be changed to ease the learning of a toothbrushing technique.

In conclusion, the participants in the present study performed brushing movements learned in group prophylaxis in childhood, but they did not perform an elaborated brushing technique, such as those taught in individual prophylaxis.

<u>Visualisation of toothbrushing</u>

In the present analysis, the characteristics of toothbrushing were visualised as a function of time, which was implemented in INTERACT. By creating these timeline charts for every participant, we obtained detailed visual impressions of the brushing process. It was easy to identify the duration and sequences of brushing locations and other co-occurring events at a glance. In contrast to the consideration of single parameters, these graphs were an impressive demonstration of the heterogeneity of brushing techniques and motion sequences. During the initial subjective and visual assessment, differences in brushing types were obvious: some participants performed frequent alternating movements between areas, some brushed for a longer time in one area, some exhibited repeating sequential brushing patterns, and some brushed systematically in order of arches or areas.

This intuitive assessment was very interesting; however, no criteria have previously existed to classify these observations. For the first time, an attempt was made to classify these visual impressions using simple criteria. To this end, brushing types were categorised as *sequential*, *systematic* and *unstructured* (see chapter 2.5.5.4).

The sequential type was defined as a brushing process that included a brushing sequence consisting of at least four batched brushing events and at least three repetitions of this sequence. For the first time, sequential analysis software (GSEQ 5.1) [Bakeman and Quera, 2013] was used to quantitatively identify participants who brushed sequentially. In contrast to the visual analysis, this software-aided method was less prone to errors and more precise, and it unveiled more participants who brushed sequentially. Because of the ability to individually set and identify the sequence of interest, this method appears to be a good means of objectively analysing the sequential brushing type.

Visually, it was easier to identify systematic brushing types than sequential brushing types. Systematic brushing was considered brushing different areas of the mouth in an ordered way without frequent alternations between the areas, with the aim of reaching every area. We visually analysed the timeline charts to identify participants who first brushed the upper, then the lower jaw, or vice versa and/or those who first brushed the oral, then the vestibular surfaces, or vice versa. The fulfilment of one of these criteria indicated a systematic brushing type. Every third participant was found to brush systematically with respect to either the jaws or surfaces. Only one participant followed the Rateitschak pattern (starting the brushing process on the oral surfaces, proceeding from sextants 6 to 1, moving to the vestibular surfaces, and proceeding from sextants 1 to 6). It is very interesting that every third participant brushed systematically; in a study of the toothbrushing behaviour of 6- to 12-year-olds in Sweden [Sandstrom et al., 2011], comparable parameters defining systematic toothbrushing were set, and every third child also brushed this way.

Participants who did not exhibit sequential or systematic brushing behaviour were classified as the unstructured brushing type. Over 50% of the participants exhibited this type of brushing process.

The various characteristics that indicate different mental or manual anchors of oral hygiene performance could also be interesting for modifying oral hygiene instruction strategies. It is possible that participants who brush systematically can best be taught using cognitive-oriented approaches, whereas those who brush sequentially can relearn their stable brushing patterns using other than conventional methods. Thus, a question arises concerning the relevance of habitual brushing characteristics for the development of successful instructions to achieve oral hygiene. A new approach to oral hygiene instruction could involve identifying an individual's pre-existing toothbrushing abilities and modifying them individually. It is helpful that the toothbrushing performance of people who already brush systematically must only be optimised because changing behaviour completely is particularly difficult and could possibly cause more inappropriate toothbrushing than before. People who brush in a sequential or unstructured pattern could be instructed by other means. It should be noted, however, that learnability could be influenced by a second factor: intraindividual differences in manual skills and dexterity.

It was obvious that the participants who brushed systematically exhibited a more structured brushing performance than those who brushed in a sequential or unstructured pattern. This finding led to the first comparison of the brushing duration between these two brushing types. Participants who exhibited a systematic brushing process brushed for a slightly longer time in every area, except the occlusal areas. The differences in the oral and anterior areas were significant. An important finding was that the duration of brushing in the oral areas was two times longer in the systematic group than in the non-systematic group but still remains insufficient. In light of the neglect of oral tooth surface brushing discussed above, the clinical relevance of maintaining a systematic brushing pattern is emphasised.

4.3.2.2 Flossing

Interproximal tooth surfaces are frequently coated with plaque and consequently have a high risk of developing caries [Kinane, 1998]. Toothbrushing alone is unable to reach the interproximal areas. To prevent this disease, the removal of plaque with the toothbrush should be complemented by the use of suitable brushing aids for interproximal hygiene [Bergenholtz et al., 1984], a practice that has become generally accepted over the years [Van der Weijden and Slot, 2011]. For this purpose, dental floss and interdental brushes are suitable, with the latter possibly being more effective [Slot et al., 2008]. In the present study, only floss was offered because *"[…]in young individuals in whom the papillae fill out the interdental spaces, dental floss is the only tool that can reach into this area[…]"* [Van der Weijden and Slot, 2011].

In 1965, a clear link between plaque and gingivitis, which is biologically plausible, was shown [Loe et al.]. However, systematic reviews and a Cochrane review that examined whether flossing contributes the reduction of gingivitis and caries produced results that were hardly encouraging, e.g., although professional flossing in children was highly effective in reducing the risk of interproximal caries, self-flossing failed to show an effect [Hujoel et al., 2006]. Moreover, routine instruction in flossing and toothbrushing, compared with toothbrushing alone, is not supported by scientific evidence [Berchier et al., 2008]. A Cochrane review assessed the effects of flossing in addition to brushing, compared with brushing alone, regarding the control of periodontal diseases and dental caries in adults [Sambunjak et al., 2011]. The results showed that *'[…]there is weak and very unreliable evidence which suggested that flossing plus toothbrushing may be associated with a small reduction in plaque at one and three months, no studies reported effectiveness of flossing plus toothbrushing for preventing dental caries*.' These studies investigated the efficacy but not the effectiveness of flossing. Thus, rather than concluding that flossing is useless, we must determine how to best instruct people in flossing. Additionally, these studies used measurements of plaque indices as a surrogate parameter for proper flossing and only examined whether, but not how, floss was used.

Only two studies have investigated flossing behaviour by observation. One study included schoolchildren aged 7-10 years [Rich et al., 1989], who were taught how to floss using a flossing technique related to the vertical flossing technique in the present study. Subsequently, the children's flossing performance was scored using a flossing dexterity index (FDI). The results showed that the flossing technique of the participants still had considerable room for improvement. The second observational study evaluated habitual flossing ability in the home environment of 246 participants aged 43.7 ± 15.9 years [Lang et al., 1995]. The subjects were asked to floss one anterior and posterior area of their mouth while being observed by an examiner. The FDI was used to determine whether their flossing was acceptable, and the following criteria were assessed: holds floss/floss holder firmly, eases floss through contact points, pushes floss subgingivally, wraps floss around line angles, and moves floss vertically against tooth. The results showed that only 22% of the participants fulfilled the criteria for acceptable flossing. However, the observation was limited to flossing dexterity with respect to specific areas of the mouth, which likely did not reflect the participants' oral hygiene behaviour as well as in the present study.

The abovementioned studies were published long ago in a different background of prevention ideas, and they included groups with different educational backgrounds.

Not only the usage of floss but a flossing technique and system that achieve the complete cleaning of interproximal spaces are particularly important. A Cochrane review related to flossing stated that *"[…]even those who do floss are often not using the proper flossing technique; for example, they quickly pass the floss through the contact points and fail to sufficiently deplaque the interdental surfaces."* [Sambunjak et al., 2011]. This statement is supported by the present results: Although 47% of the participants flossed, only one participant reached every interproximal space while performing a proper flossing technique, and only one other participant performed a proper flossing technique but did not reach every interproximal space.

The present video analysis showed that complete flossing occurred most often in the anterior teeth of the upper jaw, followed by the posterior and anterior teeth of the lower jaw. Complete flossing occurred most rarely in the posterior teeth of the upper jaw. The anterior teeth were contacted with the floss up to 37 times, whereas the posterior teeth were contacted a maximum of 7 times. It became obvious that the teeth that were the most difficult to reach and less visible in the mirror were flossed the least. A lack of understanding of the purpose of flossing also became evident: some participants flossed only the anterior interproximal spaces numerous times, and almost none of them performed a proper flossing technique.

There was an inconsistency between the reported usage of floss (42 participants reported flossing) and the actual usage of floss. Perhaps these findings could explain the hardly encouraging results in the literature. Only 31 of the 42 participants in the present study who reported flossing actually flossed during the video observation, and an additional 16 participants flossed during the video observation although they reported that they did not floss. Therefore, the number of participants assumed to floss in daily routine may have been overestimated. This theory agrees with the findings of Tedesco et al. [1991], who investigated the usefulness of a social-cognitive approach to encourage compliance with brushing and flossing behaviour recommendations. They showed that the participants exhibited positive attitudes, beliefs and norms for toothbrushing and flossing, as well as positive intentions to brush, but less intention to floss.

4.3.3 Oral hygiene status according to plaque index

It was not the aim of this study to assess dental plaque reduction by toothbrushing and flossing. Nonetheless, oral hygiene status had to be recorded to determine whether oral hygiene has to be improved at all. Dental plaque is a community of microorganisms found on tooth surfaces that are organised structurally and functionally into a biofilm [Marsh, 2006]. The stages of development biofilms range from the attachment of single bacterial cells to the tooth surface to the growth of microcolonies, resulting in a mature biofilm [Marsh and Nyvad, 2008], which occurs after 1 to 7 days. Whether dental plaque is beneficial to the host by helping prevent colonisation by exogenous species or leads to disease depends on a dynamic balance between the oral biofilm and its environment, which was shown by the ecological plaque hypothesis regarding caries and periodontitis [Marsh, 1994]. Imfeld and Lutz [1980] investigated pH changes in 2- to 6-day-old plaque using rinses with aqueous sucrose solutions. They showed that the rate and amount of intraplaque acid formation increased along with plaque age. It was also shown that the amount of supragingival plaque is a risk determinant for periodontal disease, and the higher the plaque accumulation, the higher the relevance as a risk determinant [Kocher et al., 2005]. These data indicate that established dental plaque is more pathogenic than initially formed plaque. The present results showed that the participants had a mean PI score of 1.5 ± 0.4 and a maximum PI score of 2 or higher (2.6 ± 0.48); thus, each participant had at least one tooth with visible plaque accumulation. Two-thirds of the participants even had a maximum PI of 3 (an abundance of plaque on the tooth and gingival margin, often covering the tooth surface), indicating the presence of established plaque. Consequently, the participants require improvements in their oral hygiene. Similar results were shown by the data of the DMS IV, in which teens aged 15 years had a maximum PI of 1.8 ± 0.8 [Hoffmann, 2006].

The present oral hygiene status did not conform to the previously presented results of the questionnaires concerning the oral hygiene level regarding the classification of the DMS IV into good and bad levels of oral hygiene. Therefore, over half of the participants should actually have a good oral hygiene level, which contradicts the plaque index values.

The vestibular tooth surfaces had considerably less plaque than the oral tooth surfaces. This result could be due to the oral tooth surfaces being brushed less than the vestibular surfaces in terms of both bushing duration and frequency. A second reason might be the specificity of the performed brushing strokes according to tooth surfaces. These hypotheses must be investigated further, especially by direct observation.

It must be assumed that the knowledge about oral hygiene is not in proportion to the actual oral hygiene status. A reason for this assumption could be a discrepancy between the knowledge about oral hygiene and the actual performance of oral hygiene.

Although most of the participants performed toothbrushing within the recommended brushing duration, they showed an oral hygiene status that needs improvement. There was no significant correlation between the participants' different brushing durations and their plaque index scores. On the one hand, this was expected because the effectiveness of brushing depends on additional factors, such as the reached areas. On the other hand, the plaque index was assessed before the oral hygiene performance was recorded and merely reflected the oral hygiene situation at the moment. Otherwise, a question arises concerning how the observed brushing duration is implemented in everyday life. The upper and lower jaws and the left, right and vestibular surfaces exhibited few differences in the quantity of plaque; however, significantly more plaque was found on the oral surfaces than on the vestibular surfaces. Because many participants did not reach the oral surfaces in the present setting, it can be assumed that this is the case in everyday life, which could represent a correlation with the correspondingly shorter brushing durations.

4.4 Oral hygiene instructions and learnability

The learning of an oral hygiene technique is linked to intensive instruction, which should comprise different aspects such as instruction in the performance of motor movements, motivation and target group-specific intervention strategies. It has even been shown that motivation leads to improvements in oral hygiene [Soderholm et al., 1982]; thus, more attention must be paid to promoting motivation. *“The efficiency of personal mechanical oral hygiene practices will be enhanced through an understanding of factors determining performance rather than by attempts to improve aids and techniques.”* [Sheiham and Netuveli, 2002].

Especially in children, a combination of demonstrative and verbal instruction methods are appropriate because children initially learn by imitation and absorb movement-relevant information [Annett, 1996]. Group prophylaxis is an exceptionally effective medium because it ideally includes demonstrations and an opportunity for imitation. Additionally, group prophylaxis regularly includes emotional aspects, such as a toothbrushing song or a puppet [Makuch et al., 2011], which helps capture and maintain children’s attention and eases the implementation of the demonstrated toothbrushing movements. Following group prophylaxis, individual prophylaxis, which is addressed to adolescents and adults, has the aim of advancing simple brushing movements and developing an age-based brushing technique (e.g., the Bass technique), preferably one adapted to the individual’s oral hygiene conditions. The instruction strategies are mainly cognitively oriented, and the information is usually provided in leaflets containing text or illustrated by pictures or by a demonstration of the verbally communicated instructions using a model.

In the present analysis, it was clearly shown that the filmed adolescents regularly exhibited elements of childlike toothbrushing techniques, i.e., the KAI and Fones techniques, which are regularly taught in group prophylaxis. Two questions arise due to this finding. First, why did individual prophylaxis seemingly have only a minor impact on brushing performance? Second, how can new brushing or motion sequences and brushing techniques be sufficiently implemented?

With increasing age, the learning of movements is based not only on imitation but also on aspects of imagination and cognitive processes. The movement to be learned must be executed intellectually before it can be transformed into a real movement [Annett, 1996]. This finding implies that a single demonstration is virtually unable to achieve a change or an improvement in motoric skills. Rather, a complex combination of verbalised instructions, demonstrations, intellectual imaginations of the movement and thorough training is necessary to learn and retain the new movements [Weeks and Anderson, 2000]. A new oral hygiene technique must replace the established and largely automatic motion sequences. Changing automatic processes can be quite challenging, requiring regular and effective training [Schneider and Shiffrin, 1977]. The intention is to replace the behavioural motion sequences by new ones and to transfer those newly learned sequences from the short-term memory to the long-term memory to anchor them there permanently. Tolvanen et al. [2010] put this well: To improve "*[…] oral health-related knowledge and attitudes […] oral health promotion should be designed to be a continuous process rather than a short-term intervention.*". However, only weak evidence exists that psychological intervention strategies with the aim of changing behavioural motion sequences can actually improve oral hygiene-related behaviours [Renz et al., 2007].

Regarding these considerations, it becomes obvious that the learning, internalisation and implementation of new oral hygiene techniques is a complex and multifactorial process.

These complex facts might be the reason for a lack of oral hygiene intervention success, which is commonly measured by the surrogate parameter plaque reduction and not by investigating the adoption of a brushing technique itself [Gibson and Wade, 1977;Glavind et al., 1981;Glavind and Zeuner, 1986;Harnacke et al., 2012a;Harnacke et al., 2012b]. To date, only two working groups have undertaken the complex task of teaching adequate oral hygiene behaviour, including its relation to clinical effects, its investigation in observational studies, and its relation to efficiency in plaque reduction [Schlueter et al., 2010;Schlueter et al., 2013;Graetz et al., 2013].

Conclusively, those considerations and the data from the present study lead to questions regarding the types of impact that different movement patterns have on intervention strategies. In particular, the persistence of movement patterns measured over various time points could be of major interest regarding the development of new concepts for oral hygiene education.

4.5 Conclusion and perspectives

Video observation and coding software are rarely used methods in the field of dental research, and the implementation of their combination is unique, to the knowledge of the author.

The descriptive results of the basic parameters showed that both the reported brushing duration and the actually performed brushing duration were within the time range of international recommendations. Despite this adequate brushing duration, almost every participant showed a clearly visible accumulation of plaque on the teeth and gingival margins, which suggests a general deficiency of habitual oral hygiene.

More detailed analyses of toothbrushing behaviour produced the following results. Alternations with the toothbrush between areas of the mouth were very common. The alternations often followed a repetitive scheme, which was accumulated at different areas. The most often performed brushing movements were horizontal and circular strokes. Horizontal strokes were found on vestibular and oral tooth surfaces, whereas circular strokes were found most often on vestibular surfaces.

For the first time, habitual flossing performance was observed and analysed by video observation, which revealed that nearly half of the participants flossed. Their flossing performance, however, showed deficits: only one of the participants reached all the interproximal spaces using a proper flossing technique.

This study revealed the following striking findings, which should be interpreted against the background of the literature:

1. Most of the participants neglected the oral areas of the mouth. Similar findings have been shown by publications over the last five decades to be independent of participants' socio-demographic backgrounds or experiences in oral hygiene prevention. However, these findings have not been adequately considered regarding the development of instruction strategies.
2. Specific brushing behaviours, including repetitive movement patterns, were shown by the participants. Similar observations were reported approximately 30 years ago in a comparable age group, again with only a minor impact on oral hygiene education.
3. Characteristic childlike movement patterns associated with the first education steps in group prophylaxis appeared to be implemented by most of the participants. However, further developed complex toothbrushing techniques, which should be taught in individual prophylaxis, were found quite rarely.

4. Three different types of toothbrushing behaviour were visually identified. Whereas half of the participants performed unstructured brushing, the others exhibited systematic brushing processes or repetitive sequences. These observations are described for the first time by the present work.

There is no doubt that the oral hygiene instructions need improvement to lead to appropriate tooth cleaning. The findings of the present study should be considered when developing new hygiene education: These results suggest that specific motion sequences are strongly anchored and that they occur spontaneously. It can be assumed that such patterns are linked to the close interactions among oral, facial and hand muscles, which are continuously under the control of orofacial sensory feedback; consequently, their impact should be investigated further. The question arises regarding whether these patterns could be helpful for instruction modification and could be integrated or whether they must be overcome to implement completely new motion sequences.

The methodically new analysis apparently showed three different types of toothbrushing behaviour: unstructured, systematic and sequential. Up to now, nothing is known about the conditions of their occurrence and their clinical relevance. We hypothesised that these types could be caused by different factors, e.g., cognitive, emotional or rational. Knowing more about this issue could help people alter their habitual oral hygiene to simplify the modification of the existing oral hygiene behaviour or the learning of new, proper oral hygiene behaviour.

In order to answer questions such as mentioned above, an adequate method must be used to work on the required complex analyses. The present method for analysing toothbrushing behaviour offers the possibility of differentially and objectively observing and evaluating motion sequences over a number of sessions. This possibility offers the opportunity to answer multi-layered questions concerning, for example, the persistence of movement patterns and their relevance for instruction strategies, to investigate the age- and development-associated learnability of brushing techniques for children, the motor aspects of oral hygiene of older people or oral hygiene training for people with cognitive or motor handicaps.

5 SUMMARY

The present descriptive, cross-sectional and non-disguised observational study was conducted to observe and perform a computerised analysis of the everyday toothbrushing and, for the first time, flossing habits of adolescents, who have recently reached the age of legal majority. At this age, the legally anchored prevention programme ends, and no further systematic toothbrushing assistance is provided. Therefore, 101 inhabitants of Giessen aged between 18-19 years were included.

After the plaque index was assessed according to Silness and Loe, the participants were filmed while performing their habitual toothbrushing and flossing in the dental clinic in Giessen (Germany). All the participants were aware of the filming. Subsequently, they completed questionnaires to provide their socio-demographic data and some psychological data.

The video analysis was performed with the observation software INTERACT 9. Different toothbrushing parameters, as described in literature from the seventies, were assessed, such as brushing duration, brushing movements, starting location, the frequency of alternations between areas of the mouth and flossing technique.

This study showed that the participants' brushing duration corresponded to the international recommendations; however, only a few of the participants exhibited a systematic brushing technique. The motion sequences during toothbrushing were characterised by frequent changes between the anterior and posterior areas. The brushing movements of most of the participants were characterised by elements that were taught as a part of oral hygiene education in kindergarten and primary school. Many participants did not reach all the areas, especially the oral surfaces of the posterior teeth. An interesting finding is that similar toothbrushing motion sequences performed by adolescents were observed in the late seventies [Rugg-Gunn and Macgregor, 1978;Macgregor and Rugg-Gunn, 1979a]. These sequences included the preferred brushing of vestibular surfaces, the neglect of brushing the oral surfaces and the tendency towards frequent alternations from the anterior vestibular to the posterior vestibular areas, and vice versa.

Flossing was performed by almost half of the participants, whereas a discrepancy between the self-reported and actual flossing was recognised. Five of them reached all the interproximal spaces; only two performed a correct flossing technique, and just one flossed correctly and completely. In conclusion, there was a general deficiency in flossing abilities.

For the first time, the new method used in the present work allowed the visualisation of brushing patterns, which led to a characterisation of three different toothbrushing types: systematic, sequential and unstructured movement patterns. It is conceivable that these patterns represent different predictors for the success of oral hygiene instructions.

The present results show a discrepancy between the efforts of prevention strategies regarding oral hygiene education and the actual, observed oral hygiene habits in young adults. Strategies for imparting oral hygiene techniques, especially within individual prophylaxis, should be reconsidered. The complexity of this task requires an interdisciplinary approach.

The present method for analysing toothbrushing behaviour offers the possibility of differentially and objectively observing and evaluating motion sequences over a number of sessions. This possibility offers the opportunity to answer multi-layered questions concerning, for example, the persistence of movement patterns and their relevance for instruction strategies, to investigate the age- and development-associated learnability of brushing techniques for children, the motor aspects of oral hygiene of older people or oral hygiene training for people with cognitive or motor handicaps.

6 ZUSAMMENFASSUNG

Das Ziel der vorliegenden deskriptiven, nicht verblindeten Querschnittsstudie war es, das habituelle Zahnputzverhalten und, zum ersten Mal, die Anwendung von Zahnseide bei jungen Erwachsenen am Ende der gesetzliche geregelten Prophylaxeunterstützung videobasiert und computergestützt zu analysieren. Hierfür wurden 101 Einwohner aus Gießen im Alter zwischen 18 und 19 Jahren untersucht.

Nachdem der Plaque Index nach Silness und Löe erhoben wurde, wurden die Probanden während der Durchführung ihres habituellen Putzvorgangs in der Zahnklinik in Gießen gefilmt. Alle Probanden wussten, dass sie gefilmt werden. Zum Schluss beantworteten sie soziodemographische und psychologische Fragebögen.

Die Videoanalyse wurde mit der Beobachtungssoftware INTERACT 9 durchgeführt. Verschiedene Zahnputzparameter die bereits in der Literatur in den späten siebziger Jahren beschrieben wurden, wie die Putzdauer, die Bürstbewegungen, die Startregion, die Häufigkeit der Wechsel zwischen den Mundarealen und die Zahnseidentechnik wurden erhoben.

Die Ergebnisse der Studie zeigten, dass die meisten Probanden, entsprechend den aktuellen internationalen Empfehlungen, lange genug putzten, allerdings nur wenige eine systematische Putztechnik erkennen ließen. Die Bewegungsabläufe waren durch häufige Wechsel zwischen den anterioren und posterioren Arealen geprägt. Die Putzbewegungen der meisten Probanden beinhalteten Elemente, die im Rahmen der Mundhygieneerziehung im Kindergarten und in der ersten und zweiten Klasse in Grundschulen vermittelt werden. Viele Probanden erreichten nicht alle Areale vor allem nicht die oralen Flächen der Seitenzähne. Interessant ist, dass vergleichbare Bewegungsabfolgen mit der Zahnbürste bei jungen Erwachsenen bereits Ende der siebziger Jahre beobachtet wurden [Rugg-Gunn and Macgregor, 1978;Macgregor and Rugg-Gunn, 1979a]. Darunter fallen die Bevorzugung der vestibulären Flächen, Vernachlässigung des Putzens der oralen Flächen und die häufigen Wechsel von den anterioren Regionen zur linken und rechten Seite und umgekehrt.

Nur die Hälfte der Probanden verwendete Zahnseide, wobei eine Diskrepanz zwischen berichtetem und beobachtetem Verhalten zu verzeichnen war. Fünf Probanden erreichten alle Interdentalräume, lediglich zwei zeigten die richtige Technik und nur einer von diesen zeigte die richtige Technik und erreichte alle Interdentalräume. Zusammenfassend ist festzustellen, dass ein generelles Defizit bei der Verwendung von Zahnseide zu beobachten war.

Zum ersten Mal konnte durch die im Rahmen dieser Arbeit neu entwickelte Methodik zur Visualisierung der Zahnputzabläufe eine Charakterisierung in drei verschiedene Putztypen vorgenommen werden: systematische, sequentielle und ungeordnete Bewegungsmuster. Es ist denkbar, dass diese womöglich Prädiktoren für eine erfolgreiche Mundhygieneerziehung darstellen.

Die vorliegenden Ergebnisse zeigen, dass die Ziele in Bezug auf die Mundhygieneerziehung der Gruppen- und vor allem der Individualprophylaxe bisher unvollständig erreicht wurden. Die Strategien für die Vermittlung von Mundhygienetechniken, speziell im Rahmen der Individualprophylaxe, sollten überdacht werden. Aufgrund der Komplexität dieser Aufgabe ist dazu ein interdisziplinärer Ansatz zu fordern.

Die vorgestellte Methode zur Videoanalyse bietet erstmals die Möglichkeit, Bewegungsabläufe über mehrere Sitzungen differenziert und objektivierbar zu beobachten und auszuwerten. Damit eröffnet sich der Ausblick auf die Beantwortung vielschichtiger Fragestellungen, beispielsweise zu der Persistenz von Bewegungsmustern und deren Relevanz für Instruktionsstrategien, Untersuchungen zu alters- und entwicklungsabhängiger Erlernbarkeit von Putztechniken bei Kindern, motologische Aspekte der Mundhygiene älterer Menschen oder Mundhygienetraining bei Personen mit motorischen oder kognitiven Einschränkungen.

7 REFERENCE LIST

1. American Dental Association: Brushing your teeth. http://www.mouthhealthy.org/en/az-topics/b/brushing-your-teeth.aspx; last updated: 18-2-2013.

2. Annett J: On knowing how to do things: a theory of motor imagery. Brain Res Cogn Brain Res 1996;3:65-69.

3. Attin T, Hornecker E: Tooth brushing and oral health: how frequently and when should tooth brushing be performed? Oral Health Prev Dent 2005;3:135-140.

4. Axelsson P, Lindhe J: Effect of controlled oral hygiene procedures on caries and periodontal disease in adults. J Clin Periodontol 1978;5:133-151.

5. Bakeman R, Gottman JM: Developing a coding scheme. Mutually exclusive and exhaustive codes.; Observing Interaction. An Introduction to Sequential Analysis. New York, Cambridge University Press, 1997a pp 26-27.

6. Bakeman R, Gottman JM: Observing Interaction; An Introduction to Sequential Analysis. New York, Cambridge University Press, 1997b.

7. Bakeman R, Quera V: ActSds and OdfSds: programs for converting INTERACT and The Observer data files into SDIS timed-event sequential data files. Behav Res Methods 2008;40:869-872.

8. Bakeman R, Quera V: Kappas for Point-by-Point Agreement; Event-Based Agreement for Timed-Event Sequences; Sequential Analysis and Observational Methods for the Behavioral Sciences. New York, Cambridge University Press, 2011a pp 78-81.

9. Bakeman R, Quera V: Observer Agreement and Cohen's Kappa; Observer Accuracy, Number of Codes, and Their Prevalence; Sequential Analysis and Observational Methods for the Behavioral Sciences. New York, Cambridge University Press, 2011b pp 65.

10. Bakeman R, Quera V: Observer Agreement and Cohen's Kappa; Standards for Kappa (Number of Codes Matters); Sequential Analysis and Observational Methods for the Behavioral Sciences. New York, Cambridge University Press, 2011c pp 66-68.

11. Bakeman R, Quera V: Observer Agreement and Cohen's Kappa; Summary; Sequential Analysis and Observational Methods for the Behavioral Sciences. New York, Cambridge University Press, 2011d pp 70-71.

12. Bakeman, R. and Quera, V.: GSEQ 5; Software for the Analysis of Interaction Sequences. http://www2.gsu.edu/~psyrab/gseq/index.html; last updated: 7-2-2013.

13. Bakeman R, Quera V, Gnisci A: Observer agreement for timed-event sequential data: a comparison of time-based and event-based algorithms. Behav Res Methods 2009;41:137-147.

14. Bartlett DW, Shah P: A critical review of non-carious cervical (wear) lesions and the role of abfraction, erosion, and abrasion. J Dent Res 2006;85:306-312.

15. Bass CC: The necessary personal oral hygiene for prevention of caries and periodontoclasia. New Orleans Med Surg J 1948;101:52-70.

16. Bass CC: An effective method of personal oral hygiene. J La State Med Soc 1954;106:57-73.

17. Bass CC: Personal oral hygiene; a serious deficiency in dental education. J La State Med Soc 1962;114:370-373.

18. Bauch J, Eder-Debye R, Micheelis W: Das Mundhygieneverhalten; Institut der Deutschen Zahnärzte: Mundgesundheitszustand und -verhalten in der Bundesrepublik Deutschland. Köln, Deutscher Ärzte-Verlag, 1991 pp 366.

19. Berchier CE, Slot DE, Haps S, van der Weijden GA: The efficacy of dental floss in addition to a toothbrush on plaque and parameters of gingival inflammation: a systematic review. Int J Dent Hyg 2008;6:265-279.

20. Bergenholtz A, Gustafsson LB, Segerlund N, Hagberg C, Ostby N: Role of brushing technique and toothbrush design in plaque removal. Scand J Dent Res 1984;92:344-351.

21. Bieniek KW, Kupper H, Spiekermann H: [Prophylaxis programs in the dental office--evaluation of a survey of dentists]. Dtsch Zahnarztl Z 1990;45:714-715.

22. Canadian Dental Association: Flossing & Brushing. http://www.cda-adc.ca/en/oral_health/cfyt/dental_care/flossing_brushing.asp; last updated: 1-12-2013.

23. Carvalho JC, Declerck D, Vinckier F: Oral health status in Belgian 3- to 5-year-old children. Clin Oral Investig 1998;2:26-30.

24. Carvalho JC, Ekstrand KR, Thylstrup A: Dental plaque and caries on occlusal surfaces of first permanent molars in relation to stage of eruption. J Dent Res 1989;68:773-779.

25. Carvalho JC, Ekstrand KR, Thylstrup A: Results after 1 year of non-operative occlusal caries treatment of erupting permanent first molars. Community Dent Oral Epidemiol 1991;19:23-28.

26. Carvalho JC, Thylstrup A, Ekstrand KR: Results after 3 years of non-operative occlusal caries treatment of erupting permanent first molars. Community Dent Oral Epidemiol 1992;20:187-192.

27. Claydon NC: Current concepts in toothbrushing and interdental cleaning. Periodontol 2000 2008;48:10-22.

28. Cohen J: A Coefficient of Agreement for Nominal Scales. Educational and Psychological Measurement 1960;20:37-46.

29. Cugini M, Thompson M, Warren P: Correlations between two plaque indices in assessment of toothbrush effectiveness. J Contemp Dent Pract 2006;7:1-11.

30. Currie, C., Hurrelmann, K., Settertobulte, W., Smith, R., and Todd, J.: Health and health behaviour among young people. WHO policy series: Helath policy for children and adolescents Issue 1; International report. http://www.euro.who.int/__data/assets/pdf_file/0006/119571/E67880.pdf; last updated: 15-11-2013.

31. Dahl LO, Muhler JC: Oral hygiene habits of young adults. J Periodontol 1955;26:43-47.

32. DAJ: Dokumentation der Maßnahmen in der Gruppenprophylaxe Jahresauswertung Schuljahr 2004 / 2005. http://www.daj.de/fileadmin/user_upload/PDF_Downloads/2004_2005_komplett.pdf; last updated: 12-11-2013a.

33. DAJ: Dokumentation der Maßnahmen in der Gruppenprophylaxe Jahresauswertung Schuljahr 2005 / 2006. http://www.daj.de/fileadmin/user_upload/PDF_Downloads/2005_2006_komplett.pdf; last updated: 12-11-2013b.

34. DAJ: Dokumentation der Maßnahmen in der Gruppenprophylaxe Jahresauswertung Schuljahr 2008 / 2009. http://www.daj.de/fileadmin/user_upload/PDF_Downloads/Dokumentation/Doku_2008_2009_Zahlen.pdf; last updated: 12-11-2013c.

35. DAJ: Dokumentation der Maßnahmen in der Gruppenprophylaxe Jahresauswertung Schuljahr 2009 / 2010. http://www.daj.de/fileadmin/user_upload/PDF_Downloads/Dokumentation/Doku_2009_2010_Zahlen.pdf; last updated: 12-11-2013d.

36. DAJ: Dokumentation der Maßnahmen in der Gruppenprophylaxe Jahresauswertung Schuljahr 2010 / 2011. http://www.daj.de/fileadmin/user_upload/PDF_Downloads/Dokumentation/Doku_2010_2011_Zahlen.pdf; last updated: 12-11-2013e.

37. DAJ: Dokumentation der Maßnahmen in der Gruppenprophylaxe Jahresauswertung Schuljahr 2011 / 2012. http://www.daj.de/fileadmin/user_upload/PDF_Downloads/Dokumentation/Doku_2011_2012_nur_Zahlen.pdf; last updated: 12-11-2013f.

38. Davies RM, Davies GM, Ellwood RP: Prevention. Part 4: Toothbrushing: what advice should be given to patients? Br Dent J 2003;195:135-141.

39. De la Rosa M, Zacarias GJ, Johnston DA, Radike AW: Plaque growth and removal with daily toothbrushing. J Periodontol 1979;50:661-664.

40. Dimitrova A, de Greiff A, Schoch B, Gerwig M, Frings M, Gizewski ER, Timmann D: Activation of cerebellar nuclei comparing finger, foot and tongue movements as revealed by fMRI. Brain Res Bull 2006;71:233-241.

41. Dörfer CE, Schiffner U, Staehle HJ: Häusliche mechanische Zahn- und Mundpflege - Stellungnahme der Deutschen Gesellschaft für Zahn-, Mund- und Kieferheilkunde. Dtsch Zahnärztl Z 2007;62 (9):616-620.

42. dos Santos APP, Nadanovsky P, de Oliveira BH: Inconsistencies in recommendations on oral hygiene practices for children by professional dental and paediatric organisations in ten countries. Int J Paediatr Dent 2011;21:223-231.

43. Ekstrand KR, Nielsen LA, Carvalho JC, Thylstrup A: Dental plaque and caries on permanent first molar occlusal surfaces in relation to sagittal occlusion. Scand J Dent Res 1993;101:9-15.

44. Fones AC: Dental Prophylaxis; in Fones AC (ed): Mouth Hygine, A text-book for dental hygienists. Philadelphia and New York, Lea & Febiger, 1921 pp 280-286.

45. Galinsky M, Plaschaert A, König K: Ergonomics of toothbrushing. J Dent Res 1975;54.

46. Gallagher A, Sowinski J, Bowman J, Barrett K, Lowe S, Patel K, Bosma ML, Creeth E: The effect of brushing time and dentifrice on dental plaque removal in vivo. J Dent Hyg 2009;83:111-116.

47. Ganss C, Schlueter N, Preiss S, Klimek J: Tooth brushing habits in uninstructed adults-frequency, technique, duration and force. Clin Oral Invest 2009;13:203-208.

48. Gesundheitsberichterstattung (GBE) des Bundes: 3.2.3 Zahnmedizinische Prävention [Gesundheit in Deutschland 2006]; Fig. 3.2.10: Inanspruchnahme der Individualprophylaxe (IP) durch IP-Berechtigte 1991-2003 (alte Bundesländer). http://www.gbe-bund.de/gbe10/ergebnisse.prc_pruef_verweise?p_uid=gast&p_aid=56043495&p_fid=10629&p_ftyp=TXT&p_pspkz=D&p_sspkz=&p_wsp=&p_vtrau=4&p_hlp_nr=&sprache=D&p_sprachkz=D&p_lfd_nr=391&p_news=&p_modus=2&p_window=&p_janein=J; last updated: 4-1-2013.

49. Gibson JA, Wade AB: Plaque removal by the Bass and Roll brushing techniques. J Periodontol 1977;48:456-459.

50. Glavind L, Zeuner E: Evaluation of a television-tape demonstration for the reinforcement of oral hygiene instruction. J Clin Periodontol 1986;13:201-204.

51. Glavind L, Zeuner E, Attström R: Oral hygiene instruction of adults by means of a self-instructional manual. J Clin Periodontol 1981;8:165-176.

52. Goepel C, Bertzen L: Dokumentation der Maßnahmen in der Gruppenprophylaxe Jahresauswertung Schuljahr 2006 / 2007. DAJ Infos Spezial 2008;2.

53. Goepel C, Bertzen L: Dokumentation der Maßnahmen in der Gruppenprophylaxe Jahresauswertung Schuljahr 2007 / 2008. DAJ Infos Spezial 2009;2.

54. Graetz C, Bielfeldt J, Wolff L, Springer C, Fawzy El-Sayed KM, Salzer S, Badri-Hoher S, Dorfer CE: Toothbrushing Education via a Smart Software Visualization System. J Periodontol 2013;84:186-195.

55. Grodd W, Hulsmann E, Lotze M, Wildgruber D, Erb M: Sensorimotor mapping of the human cerebellum: fMRI evidence of somatotopic organization. Hum Brain Mapp 2001;13:55-73.

56. Gülzow H.-J., Busse G.: Klinisch-experimentelle Untersuchungen über die Wirksamkeit verschiedener Zahnputzmethoden und Zahnputzmittel. Dtsch Zahnarztl Z 1970;25:1126-1134.

57. Gülzow H.-J., Keilwerth S: Über Zahn- und Mundpflegegewohnheiten von Studierenden der Universität Erlangen-Nürnberg. Dtsch Zahnarztl Z 1971;26:9-15.

58. Hamlin JK, Hallinan EV, Woodward AL: Do as I do: 7-month-old infants selectively reproduce others' goals. Dev Sci 2008;11:487-494.

59. Harnacke D, Beldoch M, Bohn GH, Seghaoui O, Hegel N, Deinzer R: Oral and written instruction of oral hygiene: a randomized trial. J Periodontol 2012a;83:1206-1212.

60. Harnacke D, Mitter S, Lehner M, Munzert J, Deinzer R: Improving oral hygiene skills by computer-based training: a randomized controlled comparison of the modified Bass and the Fones techniques. PLoS One 2012b;7:e37072.

61. Hartmann P, Schimpl-Niemanns B: Sind Sozialstrukturanalysen mit Umfragedaten möglich? Analysen zur Repräsentativität einer Sozialforschungsumfrage. Kölner Z Soziol Sozialpsychol 1992;44:315-340.

62. HBSC-Team Deutschland: Studie Health Behaviour in School-aged Children - Faktenblatt "Zahnputzhäufigkeit von Kindern und Jugendlichen". Bielefeld. WHO Collaborating Centre for Child and Adolescent Health Promotion 2012.

63. Hellwege KD: Mundhygiene und Zahngesundheit; Die Praxis der zahnmedizinischen Prophylaxe. Heidelberg, Hüthig, 1999 pp 134-135.

64. Hellwig E, Klimek J, Attin T: Einführung in die Zahnerhaltung. München, Urban & Fischer, 2006.

65. Hessisches Statistisches Landesamt, Wiesbaden: Bevölkerung Hessens nach Altersgruppen und Geschlecht. http://www.statistik-hessen.de/themenauswahl /bevoelkerung-gebiet/landesdaten/bevoelkerung-allgemein/bevoelkerung-nach-altersgruppen-und-geschlecht/index.html; last updated: 3-9-2012a.

66. Hessisches Statistisches Landesamt, Wiesbaden: Schulentlassene aus allgemeinbildenden Schulen nach schulischem Abschluss am Ende des Schuljahres 2010/11. http://www.statistik-hessen.de/themenauswahl/bildung-kultur-rechtspflege/landesdaten/bildung/allgbild-schulen/schulentlassene-allgemeinbildende-schulen/index.html; last updated: 15-8-2012b.

67. Hoffmann T: Krankheits- und Versorgungsprävalenz bei Jugendlichen (15 Jahre); Parodontalerkrankungen; Plaque-Index (PI) - Maximalwerte; in Micheelis W, Schiffner U (eds): Vierte Deutsche Mundgesundheitsstudie (DMS IV). Köln, Deutscher Zahnärzte Verlag (DZV); Institut der Deutschen Zahnärzte (IDZ), 2006 pp 230-232.

68. Honkala E: Frequency, pattern, and duration of habitual toothbrushing in children. J Pedod 1984;8:367-377.

69. Honkala E, Nyyssonen V, Knuuttila M, Markkanen H: Effectiveness of children's habitual toothbrushing. J Clin Periodontol 1986;13:81-85.

70. Hornecker E, Putz B, Attin T: Häufigkeit und Zeitpunkt des Zähnebürstens - Teil 1: aus parodontalprophylaktischer Sicht [Frequency and timing of tooth-brushing - Part I: from a periodontal preventive point of view]. Oralprophylaxe 2003;25:110-112.

71. Hujoel PP, Cunha-Cruz J, Banting DW, Loesche WJ: Dental flossing and interproximal caries: a systematic review. J Dent Res 2006;85:298-305.

72. Imfeld T, Lutz F: Intraplaque acid formation assessed in vivo in children and young adults. Pediatric dentistry 1980;2:87-93.

73. Kinane DF: The Role of Interdental Cleaning in Effective Plaque Control: Need for Interdental Cleaning in Primary and Secondary Prevention; in Lang NP, Attström R, Löe H (eds): Proceedings of the European workshop on mechanical plaque control. Status of the art and science of dental plaque control. Berlin, Quintessenz, 1998 pp 156-168.

74. Kleber CJ, Putt MS, Muhler JC: Duration and pattern of toothbrushing in children using a gel or paste dentifrice. J Am Dent Assoc 1981;103:723-726.

75. Klein S, Porst R: Mail Surveys - Ein Literaturbericht. ZUMA 2000;1-36.

76. Kocher T, Schwahn C, Gesch D, Bernhardt O, John U, Meisel P, Baelum V: Risk determinants of periodontal disease--an analysis of the Study of Health in Pomerania (SHIP 0). J Clin Periodontol 2005;32:59-67.

77. Landesarbeitsgemeinschaft für Jugendzahnpflege (LAGH): KAI-Zahnputzsystematik, Richtlinien für die Multiplikatoren in der hessischen Gruppenprophylaxe. http://www.jugendzahnpflege.hzn.de/paza_formulare/I00256B46.10/10_KAI_Kiga%20bis%20Schule.pdf; last updated: 9-8-2012.

78. Landis JR, Koch GG: The measurement of observer agreement for categorical data. Biometrics 1977;33:159-174.

79. Lang NP, Attström R, Löe H: Proceedings of the European Workshop on Mechanical Plaque Control. Berlin, Quintessenz Verlag, 1998.

80. Lang WP, Ronis DL, Farghaly MM: Preventive behaviors as correlates of periodontal health status. J Public Health Dent 1995;55:10-17.

81. Loe H: Oral hygiene in the prevention of caries and periodontal disease. Int Dent J 2000;50:129-139.

82. Loe H, Theilade E, Jensen SB: Experimental gingivitis in man. J Periodontol 1965;36:177-187.

83. Lund JP: Mastication and its control by the brain stem. Crit Rev Oral Biol Med 1991;2:33-64.

84. Macgregor ID, Balding JW, Regis D: Motivation for dental hygiene in adolescents. Int J Paediatr Dent 1997;7:235-241.

85. Macgregor ID, Rugg-Gunn AJ: A survey of toothbrushing sequence in children and young adults. J Periodontal Res 1979a;14:225-230.

86. Macgregor ID, Rugg-Gunn AJ: Survey of toothbrushing duration in 85 uninstructed English schoolchildren. Community Dent Oral Epidemiol 1979b;7:297-298.

87. Macgregor ID, Rugg-Gunn AJ: Uninstructed toothbrushing behaviour in young adults in relation to cigarette smoking in Newcastle. Community Dent Oral Epidemiol 1984;12:358-360.

88. Macgregor ID, Rugg-Gunn AJ: Toothbrushing duration in 60 uninstructed young adults. Community Dent Oral Epidemiol 1985;13:121-122.

89. Macgregor ID, Rugg-Gunn AJ: Effect of filming on toothbrushing performance in uninstructed adults in north-east England. Community Dent Oral Epidemiol 1986;14:320-322.

90. Macgregor ID, Rugg-Gunn AJ, Gordon PH: Plaque levels in relation to the number of toothbrushing strokes in uninstructed English schoolchildren. J Periodontal Res 1986;21:577-582.

91. Makuch A, Reschke K, Rupf S: Effective teaching of tooth-brushing to preschool children. J Dent Child (Chic) 2011;78:9-12.

92. Mangold: Documentation for INTERACT version 9.8 or up. Mangold International GmbH, Germany, 2009.

93. Mangold. INTERACT. 9[9.6.1.170]. Arnstorf; Germany, Mangold International GmbH. 2011.

94. Marinho VC, Higgins JP, Sheiham A, Logan S: Fluoride toothpastes for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2003;CD002278.

95. Marsh PD: Microbial ecology of dental plaque and its significance in health and disease. Adv Dent Res 1994;8:263-271.

96. Marsh PD: Dental plaque as a biofilm and a microbial community - implications for health and disease. BMC Oral Health 2006;6 Suppl 1:S14.

97. Marsh PD, Nyvad B: The oral microflora and biofilms on teeth; in Fejerskov O, Kidd E, Nyvad B, Baelum V (eds): Dental Caries; The Disease and its Clinical Management. Blackwell Munksgaard, 2008 pp 164-187.

98. McKendrick AJ, Barbenel MH, McHugh WD: The influence of time of examination, eating, smoking and frequency of brushing on the oral debris index. J Periodontal Res 1970;5:205-207.

99. Micheelis W: Aufbau der sozialwissenschaftlichen Erhebungsinstrumente; in Micheelis W, Schiffner U (eds): Vierte Deutsche Mundgesundheitsstudie (DMS IV). Köln, Deutscher Zahnärzte Verlag (DZV); Institut der Deutschen Zahnärzte (IDZ), 2006a pp 119-126.

100. Micheelis W: Aufbau der sozialwissenschaftlichen Erhebungsinstrumente. Zahnputz- und Mundhygienegewohnheiten; in Micheelis W, Schiffner U (eds): Vierte Deutsche Mundgesundheitsstudie (DMS IV). Köln, Deutscher Zahnärzte Verlag (DZV); Institut der Deutschen Zahnärzte (IDZ), 2006b pp 111-112.

101. Micheelis W, Reiter F: Mundhygienegewohnheiten; in Micheelis W, Schiffner U (eds): Vierte Deutsche Mundgesundheitsstudie (DMS IV). Köln, Deutscher Zahnärzte Verlag (DZV); Institut der Deutschen Zahnärzte (IDZ), 2006 pp 380-384.

102. Micheelis W, Schiffner U: Vierte Deutsche Mundgesundheitsstudie (DMS IV). Köln, Deutscher Zahnärzte Verlag , 2006.

103. Micheelis W, Schroeder E: Aufbau der sozialwissenschaftlichen Erhebungsinstrumente; Institut der Deutschen Zahnärzte: Dritte Deutsche Mundgesundheitsstudie (DMS III). Köln, Deutscher Ärzte-Verlag, 1999 pp 129-139.

104. Mierau HD, Haubitz I, Volk W: [Habit patterns in the use of the manual toothbrush]. Dtsch Zahnarztl Z 1989;44:836-841.

105. Mottolese C, Richard N, Harquel S, Szathmari A, Sirigu A, Desmurget M: Mapping motor representations in the human cerebellum. Brain 2013;136:330-342.

106. Muller-Bolla M, Courson F, Maniere-Ezvan A, Viargues P: Toothbrushing: which methods to use? Rev Odont Stomat 2011;40:239-260.

107. Nyvad B: Role of oral hygiene. The clinical effect of tooth cleaning; in Fejerskov O, Kidd E, Nyvad B, Baelum V (eds): Dental Caries; The Disease and its Clinical Management. Blackwell Munksgaard, 2008 pp 259-262.

108. Pieper K, Momeni A: Grundlagen der Kariesprophylaxe bei Kindern. Deutsches Ärzteblatt 2006;103.

109. Porst R: Wie man die Rücklaufquote bei postalischen Befragungen erhöht. ZUMA 2001;How-to-Reihe, Nr. 09.

110. Quintero A, Ichesco E, Schutt R, Myers C, Peltier S, Gerstner GE: Functional connectivity of human chewing: an fcMRI study. J Dent Res 2013;92:272-278.

111. Rajapakse PS, McCracken GI, Gwynnett E, Steen ND, Guentsch A, Heasman PA: Does tooth brushing influence the development and progression of non-inflammatory gingival recession? A systematic review. J Clin Periodontol 2007;34:1046-1061.

112. Rateitschak KH, Wolf HF, Rateitschak EM: Color Atlas of Dental Medicine I. Periodontology. Stuttgart, Thieme, 2004.

113. Renz A, Ide M, Newton T, Robinson PG, Smith D: Psychological interventions to improve adherence to oral hygiene instructions in adults with periodontal diseases. Cochrane Database Syst Rev 2007;CD005097.

114. Rich SK, Friedman JA, Schultz LA: Effects of flossing on plaque and gingivitis in third grade schoolchildren. J Public Health Dent 1989;49:73-77.

115. Robinson HB: Toothbrushing habits of 405 persons. J Am Dent Assoc 1946;33:1112-1117.

116. Robinson PG, Deacon SA, Deery C, Heanue M, Walmsley AD, Worthington HV, Glenny AM, Shaw WC: Manual versus powered toothbrushing for oral health. Cochrane Database Syst Rev 2005;CD002281.

117. Rugg-Gunn AJ, Macgregor ID: A survey of toothbrushing behaviour in children and young adults. J Periodontal Res 1978;13:382-388.

118. Rugg-Gunn AJ, Macgregor ID, Edgar WM, Ferguson MW: Toothbrushing behaviour in relation to plaque and gingivitis in adolescent schoolchildren. J Periodontal Res 1979;14:231-238.

119. Sambunjak D, Nickerson JW, Poklepovic T, Johnson TM, Imai P, Tugwell P, Worthington HV: Flossing for the management of periodontal diseases and dental caries in adults. Cochrane Database Syst Rev 2011;12:CD008829.

120. Sandstrom A, Cressey J, Stecksen-Blicks C: Tooth-brushing behaviour in 6-12 year olds. Int J Paediatr Dent 2011;21:43-49.

121. Saxer UP, Barbakow J, Yankell SL: New studies on estimated and actual toothbrushing times and dentifrice use. J Clin Dent 1998;9:49-51.

122. Schlueter N, Klimek J, Ganss C: Relationship between plaque score and video-monitored brushing performance after repeated instruction-a controlled, randomised clinical trial. Clin Oral Investig 2013;17:659-667.

123. Schlueter N, Klimek J, Saleschke G, Ganss C: Adoption of a toothbrushing technique: a controlled, randomised clinical trial. Clin Oral Invest 2010;14:99-106.

124. Schneider W, Shiffrin RM: Controlled and automatic human information processing: I. Detection, search, and attention. Psychological Review 1977;84:1-66.

125. Schneller, T., Micheelis, W., and Hendriks, J. Individualprophylaxe bei Erwachsenen. Erfahrungen, Problemsichten und Perspektiven bei niedergelassenen Zahnärzten. IDZ-Informationen 4. 2001.

126. Sessle BJ: Mechanisms of oral somatosensory and motor functions and their clinical correlates. J Oral Rehabil 2006;33:243-261.

127. Sharma S, Yeluri R, Jain AA, Munshi AK: Effect of toothbrush grip on plaque removal during manual toothbrushing in children. J Oral Sci 2012;54:183-190.

128. Sheiham A, Netuveli GS: Periodontal diseases in Europe. Periodontol 2000 2002;29:104-121.

129. Silness J, Loe H: Periodontal Disease In Pregnancy. II. Correlation Between Oral Hygiene And Periodontal Condition. Acta Odontol Scand 1964;22:121-135.

130. Slot D, Wiggelinkhuizen L, Rosema N, Van der Weijden G: The efficacy of manual toothbrushes following a brushing exercise: a systematic review. Int J Dent Hyg 2012;10:187-197.

131. Slot DE, Dörfer CE, Van der Weijden G, van der Weijden GA: The efficacy of interdental brushes on plaque and parameters of periodontal inflammation: a systematic review. Int J Dent Hyg 2008;6:253-264.

132. Soderholm G, Nobreus N, Attstrom R, Egelberg J: Teaching plaque control. I. A five-visit versus a two-visit program. J Clin Periodontol 1982;9:203-213.

133. Sozialgesetzbuch (SGB) Fünftes Buch (V): Gesetzliche Krankenversicherung, § 21: Verhütung von Zahnerkrankungen (Gruppenprophylaxe). [Statutory health insurance, § 21: Social Security Statute Book, fifth book; Prevention of Dental Disease (Group Prophylaxis)]. http://www.gesetze-im-internet.de/sgb_5/; last updated: 10-10-2012a.

134. Sozialgesetzbuch (SGB) Fünftes Buch (V): Gesetzliche Krankenversicherung, § 22: Verhütung von Zahnerkrankungen (Individualprophylaxe). [Statutory health insurance, § 22: Social Security Statute Book, fifth book; Prevention of Dental Disease (Individual Prophylaxis)]. http://www.gesetze-im-internet.de/sgb_5/; last updated: 10-10-2012b.

135. Staehle HJ: [Oral health behavior in Germany and Switzerland]. Schweiz Monatsschr Zahnmed 2004;114:1236-1251.

136. Tan AE, Wade AB: The role of visual feedback by a disclosing agent in plaque control. J Clin Periodontol 1980;7:140-148.

137. Tedesco LA, Keffer MA, Fleck-Kandath C: Self-efficacy, reasoned action, and oral health behavior reports: a social cognitive approach to compliance. J Behav Med 1991;14:341-355.

138. Thumeyer, A.: Kai-Zahnputzlied. http://www.jugendzahnpflege.hzn.de/frame_medien.html; last updated: 9-8-2012.

139. Thumeyer A, Buschmann C: Die KAI-Zahnputz-Systematik. Ein der Entwicklung von Kindern angepasstes Mundpflegekonzept. Oralprophylaxe Kinderzahnheilkunde 2012;34:124-128.

140. Tolvanen M, Lahti S, Hausen H: Changes in toothbrushing frequency in relation to changes in oral health-related knowledge and attitudes among children - a longitudinal study. Eur J Oral Sci 2010;118:284-289.

141. Turesky S, Gilmore ND, Glickman I: Calculus inhibition by topical application of the chloromethyl analogue of vitamin C. J Periodontol 1967;38:142-147.

142. Vaish A, Carpenter M, Tomasello M: Sympathy through affective perspective taking and its relation to prosocial behavior in toddlers. Dev Psychol 2009;45:534-543.

143. Van der Weijden F, Echeverria JJ, Sanz M, Lindhe J: Mechanical supragingival plaque control; in Lindhe J, Lang NP (eds): Clinical periodontology and implant dentistry. Blackwell Pub, 2008, vol. 2, pp 705-733.

144. Van der Weijden F, Slot DE: Oral hygiene in the prevention of periodontal diseases: the evidence. Periodontol 2000 2011;55:104-123.

145. van der Weijden GA, Hioe KPK: A systematic review of the effectiveness of self-performed mechanical plaque removal in adults with gingivitis using a manual toothbrush. J Clin Periodontol 2005;32:214-228.

146. van der Weijden GA, Timmerman MF, Nijboer A, Lie MA, Van der Velden U: A comparative study of electric toothbrushes for the effectiveness of plaque removal in relation to toothbrushing duration. Timerstudy. J Clin Periodontol 1993;20:476-481.

147. Weeks DL, Anderson LP: The interaction of observational learning with overt practice: effects on motor skill learning. Acta Psychol (Amst) 2000;104:259-271.

148. Winterfeld T, Schlueter N, Harnacke D, Illig J, Margraf-Stiksrud J, Deinzer R, Ganss C: Toothbrushing and flossing behaviour in young adults-a video observation. Clin Oral Investig 2015;19:851-858.

149. Yoder P, Symons F: Introduction and Measurement Context; Observational Measurement of Behavior. New York, Springer Pub, 2010a pp 1-16.

150. Yoder P, Symons F: Sampling Methods; Observational Measurement of Behavior. New York, Springer Pub, 2010b pp 53-71.

8 APPENDIX

8.1 Telephone protocol

Strukturiertes Telefon-Interview – Protokoll

Status: Telefonischer Erstkontakt, erledigt ☐ Termin vereinbart ☐

Kontaktdaten

Name: Probandennummer:

E-Mail-Adresse:

Telefonnr. 1: Telefonnr. 2:

Vereinbarter Termin, Datum u. Uhrzeit:

Ausschlusskriterien

Nr.	Frage an Proband	Antwort	
		Ja	Nein
A	Sind Sie 1992 geboren worden?		
B	Haben sie eine Zahnmedizinische Ausbildung?		
C	Tragen Sie eine festsitzende Kieferorthopädische Apparatur?		
D	Tragen Sie herausnehmbaren Zahnersatz?		
E	Haben sie eine Behinderung, die Sie beim Zähneputzen beeinträchtigt?		
F	Benutzen sie routinemäßig eine elektrische Zahnbürste?		

Verlauf der Kontaktaufnahme

Erst-Kontaktaufnahme durch Proband: ☐hat angerufen ☐ hat E-Mail geschickt

Nr.	Datum/ Uhrzeit	Notiz
1		
2		
3		
4		
5		

8.2 Case Report Form

CASE REPORT FORM

Untersucher:	PatCode:	Studiencode: **HTFA 1**

Fragen zum Mundhygieneverhalten

	Ja	Nein
Wurde Ihnen jemals eine Zahnputztechnik vermittelt?	☐	☐

Wenn ja, von wem? ____

Welche? ________________________________

Wie oft putzen Sie Zähne?

≥ 3xtägl. ☐ 2xtägl. ☐ 1xtägl. ☐ mehrmals/Woche ☐

1x/Woche ☐ seltener als 1x/Woche ☐ nie ☐

Wann putzen Sie Zähne?

nach dem Aufstehen/vor dem Frühstück	☐	nach dem Frühstück	☐
nach dem Mittagessen	☐	nach dem Abendessen	☐
nach Zwischenmahlzeiten	☐	bevor ich ins Bett gehe	☐
verschieden	☐		

Wie lange putzen Sie Zähne?

ca. 30 Sek.	☐	ca. 1 Minute	☐	ca. 1,5 Minuten	☐
ca. 2 Minuten	☐	ca. 3 Minuten	☐	länger als 3 Minuten	☐

Welche Mittel benutzen Sie zur Mundpflege?

Zahnbürste	☐	elektrische Zahnbürste	☐	Zahnpasta	☐
Zahnseide	☐	Zahnstocher	☐	Zahnzwischenraumbürste	☐
Munddusche	☐	Mundwasser/Spüllösung	☐	zuckerfreie Kaugummis	☐
Keine	☐				

Sonstige ______________________________________

CASE REPORT FORM

Untersucher:	PatCode:	Studiencode: **HTFA 1**

Zum Schluss bitten wir Sie noch um allgemeine Angaben zu Ihrer Person

Geschlecht
weiblich ☐ männlich ☐

Welchen Schulabschluss haben **Sie**?
(wenn Sie mehrere Schulabschlüsse haben, nennen Sie nur den höchsten)

- ☐ Volksschul- oder Hauptschulabschluss
- ☐ Abschluss 8.Klasse
- ☐ Mittlere Reife oder Realschulabschluss
- ☐ Abschluss 10. Klasse
- ☐ Fachhochschulreife (Abschluss einer Fachoberschule)
- ☐ Abitur (Hochschulreife)
- ☐ anderen Schulabschluss ________________________
- ☐ nichts davon, habe (noch) keinen Schulabschluss, gehe noch in die ____Klasse

Welchen Schulabschluss hat Ihre **Mutter**?
(wenn sie mehrere Schulabschlüsse hat, nennen Sie nur den höchsten)

- ☐ Volksschul- oder Hauptschulabschluss
- ☐ Abschluss 8.Klasse
- ☐ Mittlere Reife oder Realschulabschluss
- ☐ Abschluss 10. Klasse
- ☐ Fachhochschulreife (Abschluss einer Fachoberschule)
- ☐ Abitur (Hochschulreife)
- ☐ abgeschlossenes Studium
- ☐ keinen Schulabschluss
- ☐ weiß nicht

Welchen Schulabschluss hat Ihr **Vater**?
(wenn er mehrere Schulabschlüsse hat, nennen Sie nur den höchsten)

- ☐ Volksschul- oder Hauptschulabschluss
- ☐ Abschluss 8.Klasse
- ☐ Mittlere Reife oder Realschulabschluss
- ☐ Abschluss 10. Klasse
- ☐ Fachhochschulreife (Abschluss einer Fachoberschule)
- ☐ Abitur (Hochschulreife)
- ☐ abgeschlossenes Studium
- ☐ keinen Schulabschluss
- ☐ weiß nicht

9 LIST OF PUBLICATIONS

Article

T. Winterfeld, N. Schlueter, D. Harnacke, J. Illig, J. Margraf-Stiksrud, R. Deinzer, C. Ganss: Toothbrushing and flossing behaviour in young adults-a video observation. Clin Oral Investig 2015;19:851-858.

Abstracts

T. Winterfeld, R. Deinzer, C. Ganss, D. Harnacke, J. Margraf-Stiksrud, N. Schlueter, J. Illig: Video analysis of toothbrushing and flossing habits in adolescents. Caries Res 2012;46:268-338; Abstract 102.

T. Winterfeld, N. Schlueter, J. Klimek, C. Ganss: Consistency of toothbrushing habits: a pilot video analysis study. Caries Res 2013;47:433-531; Abstract 163.

T. Winterfeld, N. Schlueter, K. Winterfeld, C. Ganss: Effect of systematic toothbrushing on changes of toothbrushing behaviour and relation to plaque. Accepted for Caries Res 2014;49; Abstract 63.

Posters

T. Winterfeld, R. Deinzer, C. Ganss, D. Harnacke, J. Margraf-Stiksrud, N. Schlueter, J. Illig: 'Video analysis of toothbrushing and flossing habits in adolescents'. Presented at a congress of the 59th European Organisation for Caries Research (ORCA) 2012 in Cabo Frio, Brazil.

T. Winterfeld, N. Schlueter, J. Klimek, C. Ganss: 'Consistency of Toothbrushing Habits: A Pilot Video Analysis Study'. Presented at a congress of the 60th European Organisation for Caries Research (ORCA) 2013 in Liverpool, England.

Awards

Wrigley Prophylaxe Preis 2012 (Bereich Wissenschaft: Sonderpreis); Winterfeld T, Ganss C, Schlueter N, Margraf-Stiksrud J, Illig, J: „Mundhygieneverhalten junger Erwachsener – eine Videoanalyse“.

Junior Scientist's Award at the 60th congress of the European Organisation for Caries Research (ORCA) 2013 in Liverpool. Poster und Kurzvortrag: 'Consistency of toothbrushing habits: a pilot video analysis study'.

Lecture

„Können junge Erwachsene Zähne putzen? Eine Videobeobachtung"; T. Winterfeld: GABA-Symposium „Update Mundhygiene"; erste Gemeinschaftstagung der Deutschen Gesellschaft für Zahnerhaltung (DGZ), der Deutschen Gesellschaft für Endodontologie und zahnärztliche Traumatologie (DGET) und der Deutschen Gesellschaft für Präventivzahnmedizin (DGPZM) in Marburg, 2013.

10 ERKLÄRUNG ZUR DISSERTATION

„Hiermit erkläre ich, dass ich die vorliegende Arbeit selbständig und ohne unzulässige Hilfe oder Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Alle Textstellen, die wörtlich oder sinngemäß aus veröffentlichten oder nichtveröffentlichten Schriften entnommen sind, und alle Angaben, die auf mündlichen Auskünften beruhen, sind als solche kenntlich gemacht. Bei den von mir durchgeführten und in der Dissertation erwähnten Untersuchungen habe ich die Grundsätze guter wissenschaftlicher Praxis, wie sie in der „Satzung der Justus-Liebig-Universität Gießen zur Sicherung guter wissenschaftlicher Praxis“ niedergelegt sind, eingehalten sowie ethische, datenschutzrechtliche und tierschutzrechtliche Grundsätze befolgt. Ich versichere, dass Dritte von mir weder unmittelbar noch mittelbar geldwerte Leistungen für Arbeiten erhalten haben, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen, oder habe diese nachstehend spezifiziert. Die vorgelegte Arbeit wurde weder im Inland noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde zum Zweck einer Promotion oder eines anderen Prüfungsverfahrens vorgelegt. Alles aus anderen Quellen und von anderen Personen übernommene Material, das in der Arbeit verwendet wurde oder auf das direkt Bezug genommen wird, wurde als solches kenntlich gemacht. Insbesondere wurden alle Personen genannt, die direkt und indirekt an der Entstehung der vorliegenden Arbeit beteiligt waren. Mit der Überprüfung meiner Arbeit durch eine Plagiatserkennungssoftware bzw. ein internetbasiertes Softwareprogramm erkläre ich mich einverstanden.“

Ort, Datum

Unterschrift

11 ACKNOWLEDGEMENTS

First of all, I would like to express my sincere gratitude to my dissertation supervisor Professor Dr. Carolina Ganss, for her scientific inspiration, her excellent support and her encouragements for both the progress of the thesis and my additional scientific research.

I am also grateful to my second supervisor PD Dr. Nadine Schlueter, for her constructive criticism helping to enrich the quality of the thesis and her friendly working relationship.

Special thanks go to Professor Dr. Joachim Klimek, for the opportunity to conduct the study in his department and his funding for my research.

I am deeply grateful to my parents, who have enabled my studies. They are supporting me in every life situation.

I would like to express my deepest appreciation to my wife Katrin, for her motivation and mental support, and the insightful discussions about the thesis.