Curr Oral Health Rep (2015) 2:123–128
DOI 10.1007/s40496-015-0053-z

DENTAL PUBLIC HEALTH (A PINTO, SECTION EDITOR)

Drilling Deeper into Toothbrushing Skills: is Proactive Interference an Under-Recognized Factor in Oral Hygiene Behavior Change?

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Published online: 23 July 2015

Abstract Proper toothbrushing is a seemingly simple motor activity that can promote oral health. Applying health theories, such as the *Information-Motivation-Behavioral Skills* (IMB) model, motivational interviewing (MI), and integrative health coaching (IHC), may help optimize toothbrushing technique in those with sub-optimal skills. Some motor activities, including toothbrushing, may over time become rote and unconscious actions, such that an existing habit can inhibit new learning, i.e., exert *proactive interference* on learning the new skill. Proactive interference may impede the acquisition of new toothbrushing skills; thus, in this report, we (1) review how the habit of toothbrushing is formed, (2) postulate how proactive interference could impede the establishment of proper toothbrushing retraining, (3) discuss the merits of this hypothesis, and (4) provide guidance for future work in this topic within the context of an approach to behavior change that integrates IMB, MI, and IHC methodology.

Keywords Toothbrushing · *Information-Motivation-Behavioral Skills* model · Integrative health coaching · Proactive interference · Learning · Memory

This article is part of the Topical Collection on *Dental Public Health*

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Background

Oral health is an essential component of overall health [1]. Poor oral health can affect one's quality of life, social functioning, physical and psychological health, as well as one's economic opportunities [2]. Toothbrushing is a commonly employed physical behavior to promote optimal oral health. Normal toothbrushing practices can be adequately performed by most adults to control the build-up of bacterial bio-film on teeth and thus lower the risk for gingivitis and possibly periodontal disease [3••]. While several toothbrushing methods have been recommended, each has its own advantages and disadvantages, and there is no uniform consensus on which method is best [3••].

A common challenge for dentists is to encourage more optimal oral hygiene practices for their patients [2]. While traditionally, the dental community may attribute oral hygiene deficits to a lack of patient motivation [4], others have questioned whether more attention should be focused on the skill and technique of toothbrushing [5••]. Providing information (i.e., knowledge, facts) alone has had little impact on changing patient behavior [6]. Regarding the common lack of long-term influence on changing oral hygiene behavior, investigators have proposed poor motivation, a lack of sufficient motor skill, the need for behavioral modification, as well as interference due to cognitive effects and muscle memory [7, 8, 9••]. Nonetheless, to date,

there has been no comprehensive explanation as to why skill-based behavior change, in the context of oral health, can be so challenging; typically, providers may assume a lack of patient motivation, but have we given enough attention to skill and changing old habits? Herein, focusing on skill acquisition, we propose an explanation and a methodology to help promote proper toothbrushing behavior change in adults.

Foundational Health Theory for Behavior Change

There is a general consensus that strategies to promote health behavior changes should be based on behavioral theory [10, 11]. We suggest that oral health behavior change be based on the *Information-Motivation-Behavioral Skills* (IMB) model proposed by Fisher et al. 2009 [4]. That is, that in the context of promoting enhanced toothbrushing technique, the provider should (1) communicate information—i.e., explain, in plain language, the presence of oral disease and how toothbrushing can promote oral health in, for example, specific areas where the patient has gingival inflammation; (2) promote personal or intrinsic motivation to learn proper toothbrushing technique and encourage positive attitudes concerning toothbrushing and performing this behavior each day; (3) ensure that all phases of the behavioral skill of toothbrushing (including having the needed supplies, having time and space to do the activity, having the perceived self-efficacy to perform the task properly) are understood and can be performed even in light of any personal or environmental challenges [4]. In this IMB-focused context, we further suggest using the spirit of and techniques consistent with motivational interviewing (MI) [12] and integrative health coaching (IHC) (see Simmons and Wolever, 2013 and Howard, 2015) [13••, 14••], as well as a humane, personal, and flexible approach/philosophy as detailed in Vernon et al. 2013 [5••] (for a trans-disciplinary integration of the above health theories/coaching in the dental setting, see Vernon and Howard, in this issue). Within the framework described above, we will, herein, focus specifically on *behavioral skills*, the final element of the IMB model [4], and an essential component enabling patient engagement in behavior change interventions [15•].

Drilling Deeper—Visual-Motor Learning and Memory

Toothbrushing, a learned behavior, is usually introduced to the child with adult supervision, early in life. Over time, a toothbrushing habit is formed as a common routine [16]; this habit may later become relatively automatic and resistant to change [13••]. Studies examining toothbrushing behavior on a population level indicate that the toothbrushing habit results from a repeated and patterned sequence of behavior over time [17–20]. A large proportion of the population may be mostly unaware of aspects of their own toothbrushing behavior—and this is very similar to most, if not all, routine behaviors [19, 20]. When a given procedure is repeated at regular intervals, it tends to become largely sub-conscious or "automatic" [16]. Because of this automatic nature, patients often tend to improperly estimate the features associated with their toothbrushing [18, 19]. For example, in a study by Saxer et al. 1998, most patients attending a private dental clinic setting in Switzerland in the 1980s and 1990s overestimated the duration of their toothbrushing [19]. A recent systematic review concluded that among clinical prevention and health education, MI, counseling, and behavior change models, MI interventions were found to be the most effective approach to altering patient behavior to promote oral health [20]. However, Tedesco et al. 1992, reporting on social cognitive interventions to promoting new toothbrushing practices, found that cognitive restructuring interventions often failed and subjects reverted back to their original habit by end of the 9-month follow-up period [21]. These data suggest that, by virtue of its early initiation, the regularly repeated act of toothbrushing becomes a part of a human memory system termed implicit memory [22, 23]. Implicit memory is a subtype type of long-term memories. Actions and behaviors influenced by the imprint of previous experience (i.e., information and neural processing that often cannot readily be expressed in words) aid the repeated performance of the task over time and may be performed largely without conscious awareness of the previous experiences [22]. Such tasks include emotional memories (learned emotional responses to various stimuli—through classical conditioning) as well as procedural memory (motor skills and habits, including toothbrushing) [23]. The procedural type of memory is processed by the cerebellum [22–25]. In the psychological and memory literature, toothbrushing has been reported as a procedural and implicit type of memory [23, 24].

Existing Memories and New Learning; Proactive Interference

Further, memory has three distinct stages: (1) encoding, (2) consolidation, and (3) retrieval [22]. Each type of memory has a distinct pathway for these three stages. In the brain, specific memory processes may interfere with each other [24]. Proactive interference refers to a situation in which "the information that one has accumulated in the past makes it more difficult to acquire new information"; whereas, retroactive interference "is a situation in which the acquisition of new information makes it difficult to perform or recollect older information" [24]. For example, the challenge of recalling a new telephone number is an example of proactive interference. The memory of the old number interferes with the recalling of the new number. Once one has successfully learned to recall the new telephone number, there may be some trouble to recall the old number—and this is retroactive interference.

Working Hypothesis

When a new toothbrushing technique and/or a modification of existing toothbrushing technique is learned by an adult subject, the person's implicit memory (see above) may not, especially in certain individuals, be easily altered. Though the cause of this phenomena is poorly understood, many suggestions have been proposed [5••, 7, 8, 9••, 26–30]. It is possible that, for example, as a child ages and his/her level of skill improves, he or she may develop effective toothbrushing skills [26, 27]; however, once ineffective skills are developed, it may be difficult for an adult to alter his or her established oral hygiene practices—i.e., an adult with an ingrained habit may have less learning plasticity as compared to a child or adolescent [31]. Furthermore, to date, to our knowledge, few investigators have viewed toothbrushing as a routine habit through a prism of procedural-implicit memory.

The updated 1986 Norman-Shallice-Cooper model has previously described in detail the toothbrushing habit formation [14••, 32, 33]. Toothbrushing, as explained earlier, is introduced to the child under adult supervision and is repeated over years. Over time, toothbrushing becomes a routine behavior, the act of which is largely performed as an unconscious act [7]. If the toothbrushing habit has been previously learned "improperly," the patient (now an adolescent or adult) may be taught the ideal technique by an oral health care provider and have the motivation to retrain him or herself to develop a more ideal toothbrushing technique. Such an endeavor may typically be followed by positive reinforcement and refinement in technique over time under the ongoing supervision of an oral health care provider. We hypothesize that in this initial stage (or in the initial days of technique adjustment), the patient may be diligent, careful, and conscientious when toothbrushing. At this initial relearning stage, toothbrushing is performed as a conscious act, overseen by the patient's cognitive and higher executive function centers of the brain until this new process becomes a newer or updated procedural memory, i.e., a relatively rote task. In a majority of the people, we hypothesize that, before the new toothbrushing technique becomes an integral part of implicit procedural memory (which includes numerous functions such as encoding, storage, and retrieval), proactive interference may exert a strong influence, especially in some people. Owing to the strong influence of proactive interference and reduced performance due to retroactive interference, the patient may tend to *revert back* to the old toothbrushing technique (i.e., like the old saying "old [motor] habits die hard"). We predict that proactive interference, if present, would adversely impact the storage and retrieval components of procedural-implicit memory within the context of learning a new technique.

With regard to the subset of patients who found it relatively easy to adapt to the newer, correct toothbrushing technique, we hypothesize that such patients would have had stronger changes in any or all of the memory-forming stages involved in achieving an improved toothbrushing technique. In such a situation, proactive interference would be neutral or inactive. The patient attributes of such a subset people should be characterized. For example, (1) were such patients highly motivated? (2) Were patients actively engaged? [15•] (3) What components of the training were resonant with the given individual? [8] (4) Had the patient been "activated" prior to the training by proper message framing [34••]?

Evaluation of the Working Hypothesis

In sports and motor skill literature, technical errors have been referred as recurrent or expert errors [35]. Proactive and retroactive interference effects have been noted in several sports, including swimming, javelin, and tennis [36–38]. In this context, expert errors are corrected by doing specific drill work, reteaching by repetition of skills (often sub-skills) that are isolated and performed in a more optimal manner. In spite of repeating new skills for about a year, it has been documented that athletes can switch back to old incorrect habits. In a study conducted in 1989 among seventh and eighth graders who learned backhand stroke in tennis, the presence of proactive interference was confirmed [36]. Lyndon's "old way/new way" is a method that would make the learner aware of his/her behavior and isolate the specific component of the habit that needs to be improved. The "old way/new way" theory explains how a repetitive conscious act would help to minimize specific errors embedded in a motor skill that involve cognition, memory, and proactive interference—as well as, potentially, accelerated forgetting [36–38]. The old way/new way approach to learning new skills or techniques has been reported to be successful in several sports wherein a trainer corrected previously improperly learned skills that had a negative impact on the athlete's performance. For example, showing a wrong "old way" and teaching a correct "new way" using video filming was implemented in a world-class swimmer whose start (i.e., jump, height, and angle) needed to be adjusted in order to swim a faster race time. The viewing of the new and old techniques in filmed videos helped the swimmer to perform correctly and swiftly within a very short time period. Specifically, the commonly used start (out of the water, from the starting block) was not well suited for the athlete's physical dimensions; hence, for more optimal performance, an individualized start from the starting block was designed for his unique characteristics and was learned and used successfully [35]. Thus, Lyndon's technique of inhibiting proactive inhibition was used to correct suboptimal habits in elite swimmers [35, 38]. This concept has been increasingly drawing attention in sports psychology, especially in regards to learning motor skills [39].

Toothbrushing skills may be seen as being similar to the skills involved in swimming, as both involve motor skills and

may be stored as an implicit procedural memory. A poorly learned skill or automatic error develops due to repeated performance of any improperly learned technique or skill. As the suppression of proactive interference has been a core of the successful Lyndon's technique, this concept may be applicable to learning a new and more effective method of toothbrushing [35]. Cinar et al. 2009 studied toothbrushing using the social cognitive theory among Finnish (n=338) and Turkish (n=611) preadolescents and their mothers to identify the social and cognition factors of toothbrushing. They concluded that though socio-cultural factors were different, cognition in this aspect were nearly similar. Thus, this study emphasized the importance of cognition in toothbrushing. [40].

A neuro-cognitive experiment by Cothros et al. 2006 demonstrated that proactive interference is related to the retention of newly learned motor skills in certain regions of primary motor cortex in brain [41]. They, along with others, have demonstrated that proactive interference is caused by the effects of persistence of neural representations of learned skills that impede the gaining of new neural representations associated with newly learned skills [41, 42]. Further, Cohen et al. 2007 has suggested that, in the consolidation phase of the new procedural memory, there could be a competitive interaction between distinct components of an existing ("old") memory [43]. By application, a suboptimal consolidation of an existing ("old") with a new toothbrushing memory may prevent the new toothbrushing memory from being enhanced. As well, such an interaction has been reported to occur during memory encoding [44]. Applying the conclusions of these studies to our hypothesis, we suggest that the strong neutrally represented ("old") toothbrushing method could deter or prevent the full formation of a neural representation of a newer and more effective toothbrushing method.

Consequence and Discussion

Based on the above studies [43, 44] and prior text, we propose that, during an attempt to modify the toothbrushing habit (and especially during the formation and consolidation phases), proactive interference should be kept to a minimum. Simple techniques may help to minimize proactive interference, for example: having a disruption in the regular sequence of actions—such as a shift in the practice time, place, and sequence of toothbrushing—could be employed. To date, there is no evidence to establish that such an approach would work; however, if demonstrated to be effective, such an intervention (or others) may help dissociate the contextual clues associated with the existing ("old") toothbrushing habit and thus, potentially, help keep proactive interference to a minimum.

Procedural memory formation, encoding and retrieval (especially the "unconscious" part) has been explained using the elaboration hypothesis, the reconstruction hypothesis, the retroactive inhibition hypothesis, and Schmidt's schema theory [45]. The clinical significance of understanding the phenomenon of procedural memory formation has been shown to be vital to treat motor skill disabilities in disorders such as Parkinson's disease as well as to improve fine motor skill involved in sport activities [35–37, 41, 45, 46]. Thus, understanding how simple motor skill memories are formed and retrieved could elucidate how motor skills can most easily be acquired during retraining (especially for relatively simple skills).

In spite of having adequate knowledge, a strong motivation, sufficient motor skills, and a positive behavioral attitude, a small subset of subjects may not be easily able to fully integrate proper toothbrushing skills into their existing habit. The previously learned toothbrushing motor skill and procedural memory may impede the learning, encoding, and retrieval of procedural toothbrushing memory. Proactive interference could be a factor silently impeding the learning and adaptation of toothbrushing skills.

One simple way to investigate this topic further is to quantify the "old" toothbrushing habit as well as the "new technique" using a valid and reliable directly observed measure of toothbrushing skill—to determine what type of intervention fosters the greatest shift to the new technique and helps to maintain the new technique over time. For example, which specific factors yield the greatest shift? Using longitudinal studies, is such a shift dependent on: (1) information given to the patient; (2) motivation of the patient; (3) the type, duration, or intensity of training (i.e., behavioral skills coaching); (4) patient engagement [15•]; (5) health message framing [34••]; (6) trainer characteristics; (7) learner characteristics; (8) other variables, or (9) some combination of the above? Further, investigators could assess the degree of "backwards drift" (from "new" to "old" toothbrushing technique). To what degree does "muscle memory" help or hinder the learner over time during retraining? Does this occur in certain people—or, to some extent, all people? What kind of learning overpowers the power of habit? And what factors most effectively reduce the chance for "backwards drift" into improper toothbrushing technique after completion of a retraining intervention? Are certain people more prone to "relapse," or is this more dependent on the methodology, specificity, duration, or intensity of the training? Further, can the "old" and "new" way of toothbrushing be quantified using functional magnetic resonance imaging (fMRI) or a similar new technology? And finally, does a directly-observed (by the provider) measure of toothbrushing skill (1R21DE023740) correlate with the results of fMRI or other new technologies? Many questions can be asked to drill deeper into this topic, and findings may help reinforce skill acquisition in oral health and, potentially, other areas of health promotion.

Pending completion of valid and reliable studies in the future that have demonstrated results consistent with our current working hypothesis, effective ways to curb proactive interference when learning new toothbrushing techniques can be developed. For example, such methods may include (1) videotaping the old way/new way approach and reviewing the session with the

patient, (2) isolating specific skill deficits and suggesting discrete training exercises, or (3) using a toothbrush with an unusual handle or head—to alter one's "sensory feel"—and make the training a relatively "new experience." Such approaches may help the patient to more efficiently and effectively shift from a suboptimal brushing technique to a better brushing technique that should promote better long-term oral health.

Conclusion

Correction of improper toothbrushing (i.e., optimal retraining) may be effectively learned when the subject is informed, motivated, and aware of specific behavioral skills—such that the proper toothbrushing method is effectively coded and retrieved (i.e., keeping proactive interference to a minimum). To date, the existence of proactive interference during toothbrushing skill retraining has not been considered. Our current working hypothesis could help provide a more dynamic understanding of how oral health providers should approach and structure toothbrushing education. Further research findings investigating the presence and extent of—as well as ways to minimize—proactive interference may yield clues for enhanced retraining of proper toothbrushing technique.

Acknowledgments We thank the organizing committee of the 7th World Workshop on Oral Health and Disease in AIDS (that took place in Hyderabad, India, November 6–9, 2014) for allowing the opportunity for Drs. Thavarajah and Vernon to meet and thus collaborate on this manuscript.

Compliance with Ethics Guidelines

Conflict of Interest Rooban Thavarajah, Madan Kumar, Anusa Arunachalam Mohandoss, and Lance T. Vernon have declared that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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