# Tooth brushing as routine behaviour

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Regular tooth brushing is considered an excellent preventive measure for oral plaque control. Yet despite over one hundred years of effort by dental professionals, levels of tooth brushing remain distressingly low. Evidence from a variety of studies suggests that tooth brushing is commonly performed in a regularised, automatic (i.e., routine) manner. Here it is argued a routine can be considered a recurring sequence of behaviours produced in conjunction with a script (or group of behaviours hierarchically represented in memory), and controlled as a unit or 'chunk'. A robust model of routine behaviour is presented, the Norman-Shallice-Cooper model, which is then applied to the example of tooth brushing behaviour, suggesting a variety of strategies for introducing tooth brushing into daily routines. Empirical studies are also reviewed which suggest that tooth brushing practices cluster in families. This clustering, together with the persistence of the practice throughout life, is consistent with the hypothesis that tooth brushing typically occurs within family-based traditions. Clinical and public health efforts in dentistry can therefore potentially be made more effective by taking into consideration how routines are created and then maintained within family or school environments.

*Key words: Tooth brushing, behaviour, scripts, routine*

Regular tooth brushing is considered the best preventive measure for oral plaque control. Brushing twice a day with a fluoridated toothpaste is the current clinical recommendation[1,2]. Three-quarters of British adults claim to brush their teeth twice a day[2]. However, this is only reported behaviour; actual tooth brushing is probably lower, as suggested by the fact that the prevalence of plaque and periodontal disease remains high: in the UK, 72% of adults and 33% of teeth have visible plaque, and 54% of adults have pocketing greater than 3.5mm[3]. Thus, significant proportions of this population do not brush twice daily, despite many years of promoting the recommended norms. The situation is considerably worse in the developing world[4].

A major problem in preventive dentistry is therefore how to increase the proportion of a population regularly engaging in oral hygiene self-care[5-8]. Dental health professionals need to find an effective means of inducing sustained tooth brushing and flossing, especially at large scale.

Within populations, better oral hygiene behaviour is associated with being female, better educated, and relatively wealthy[9,10]. However, these factors are not amenable to change through interventions. Further, adherence to medical regimens tends not to depend on stable individual-level characteristics such as health beliefs, demographic qualities, or personality traits[11]. It is therefore difficult to target specific segments of a population with particular interventions. This difficulty has led to calls for dental hygiene to stop focussing on individual behaviour-change and rather engage in group-level promotion efforts[12-14]. However, variation in levels of oral hygiene practice between populations seems to be primarily explained by cultural traits and traditions[15]. These factors, too, are relatively immune to intervention, suggesting that community-level dental promotion may also be difficult to implement.

This paper argues that a more reasonable target of oral hygiene self-care efforts is neither individuals nor groups, but families. Exhibiting the practice of brushing teeth is likely to be a function of whether an individual's parents brushed their teeth – that is, tooth brushing is likely to follow a pattern of family-based traditions. This is because tooth brushing and flossing are routine behaviours which may be best inculcated in children by parents.

A variety of studies suggest that tooth brushing is commonly routinised. Analysing the tooth brushing


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behaviour of a number of individuals revealed that their behaviour formed a standardised sequence of actions at several levels of description[16]. People are also unaware of aspects of their own tooth brushing behaviour – as expected of routine behaviours, which, because they are repeated regularly, become largely subconscious. For example, people tend to overestimate the amount of time they spend brushing[17,18].

Tooth brushing also appears to be inculcated early in life and then to resist alteration. For example, good oral hygiene behaviour in childhood was a significant predictor of periodontal health status ten years later in a sample of Danish people[19]. A routine can also be quickly learned: intensive dental interventions seem to be hardly any more effective than one-shot interventions[20,21]. Further, inducing tooth brushing in children and adolescents is more successfully achieved by emphasising imitation or behaviour modification than education[22]. It is also difficult to alter established oral hygiene practices in adults[23,24]. In adults, practices initiated by an intervention tend not to persist after the intervention[25-27]. Thus a systematic review of studies looking at the utility of professional instruction on tooth brushing behaviour showed only a very small reduction in gingivitis in adults compared to controls[28]. Finally, establishing dental habits probably occurs in a familial context. Thus the inter-dental cleaning practices of children are highly correlated with that of their mother, for example[29]. These studies suggest that tooth brushing practices cluster in families. This clustering, together with the persistence of the behaviour throughout life, is consistent with the hypothesis that tooth brushing occurs within family-based traditions.

Inculcating routine practices should thus persist within families as children grow up to become parents themselves, and pass the tradition along. What dental hygiene programmes really want to create is a population with tooth brushing habits – or a tendency to respond to particular, recurrent cues in their daily environment by brushing their teeth. I will therefore argue that interventions to modify tooth brushing behaviour should rely on techniques based on routine modification that families can implement. What we need to know is how to best help people create new routines in themselves and those they care for. Dental hygiene improvement programmes should therefore either target mothers of young children to become toothbrush teachers for their offspring, or target children themselves, presumably in school, which is becoming an increasingly popular option[30]

The remainder of this paper is therefore devoted to presenting a model of routine behaviour, and showing how such routines can be modified. The model of routine behaviour formation or modification is then applied to efforts to improve oral hygiene self-care. Evidence is also presented which suggests that tooth brushing interventions have been effective to the degree that they have at least implicitly considered the routine nature of tooth brushing. This evidence suggests that visits to the dentist and dental health intervention programmes can potentially be made more effective by taking into consideration how routines are created and then maintained within family or school environments.

## Routine behaviour

Efforts to change any behaviour should begin with an understanding of how it is caused. A routine is a recurring sequence of behaviours controlled as a unit or 'chunk'. Routine behaviour occurs on an everyday basis, typically in a regimented manner. In particular, it follows a standard sequence of actions which can be analysed in hierarchical fashion.

Like other kinds of behaviour, routine behaviour is produced by structures in the brain; evolutionary pressures experienced by our ancestors required them to survive by producing appropriate responses; over time, brain structures that produced appropriate responses formed[31,32]. In higher animals, these structures can rely on memories of previous experiences in similar situations to guide selection of the appropriate behaviour. A widely-accepted hypothesis is that these memories are hierarchical in nature, to enable the production of regularised sequences of behaviours – i.e., routines. These memory structures are called 'scripts'[33,34]. The model of routine behaviour causation adopted here is thus that significant stimuli trigger an appropriate brain structure which relies on scripts to determine the appropriate sequence of actions to take in response. In this section, I will first explain the hierarchical structure of brains in greater detail, and then go on to discuss the scripts on which they rely.

### *Levels of control over behaviour*

Reactions to complex situations can require sequences of appropriate responses as situations develop. To cope with the problem of producing behavioural sequences, a number of scholars have assumed the existence of hierarchical control over behaviour, both in psychology[34-37] and animal behaviour[38,39]. More recently, a number of different initiatives in psychology[40-42], neuroscience[43], and robotics[44-46] have converged on a three-layered information-processing architecture to provide this hierarchical control. This is because such three-level architectures have the best record of producing complex, adaptive behaviour in both organisms and artificial agents. For example, the most robust three-level model in psychology, the Norman-Shallice-Cooper ('NSC') model, has been implemented computationally and applied to relatively complex real-world tasks (such as making tea)[41], while robots with such architectures have been sent to dangerous locales[44] or other planets[45], where they have managed to function autonomously. This architecture is also consistent with what we know about the evolutionary history of brains, which suggest that these levels of control in human brains arose at distinct points in time[47].

The three levels of control are:

- Cognitive
- Motivated
- Reactive.

In human brains, the bottom layer of control (and oldest in evolutionary terms) is reactive. It couples motor outputs tightly to sensory inputs, and produces 'atomic' actions (i.e., those not further reducible from a functional point of view, except into motor control programmes – e.g., 'blink eyes'). These actions are well tailored to their context by a long history of natural selection. They are presumably implemented by relatively simple neural circuits[47,48]. Execution of reactive behaviour need not require recalling information from memory (or indeed internal representations of any kind); hence it enables a quick response, based strictly on environmental cues.

The middle level of control, called 'motivational', produces goal-directed behaviour. Goal pursuit can be necessary when persistent behaviour is warranted so that a particular end-state can be achieved even though the environment is changing. Goals allow alternative means to be specified for achieving a given end-state, providing some degree of flexibility in behaviour and avoiding the need to specify the course of action in detail.

The highest level of control, called 'cognitive' here, only evolved recently in our primate ancestors[40]. It provides long-term planning and problem-solving abilities. Cognition can represent abstract objectives and intervene to take control in situations when automatic responses are not appropriate (i.e., when discrepancies between an animal's current state and needs are detected). It can override motivated action in favour of a better long term outcome. Cognitive control can make use of memory and imagination – that is, information about both past and future, expected events. It also monitors the execution of scripts and detects failures to achieve goals[49]. Cognition is thus tightly coupled to attentional alarms that can reach down to interrupt reflexive activity (i.e., a vigilance system with an 'override' ability)[50,51]. Cognition thus activates lower-level processes which would not otherwise be triggered by a situation, or can inhibit those processes which would normally be activated in order to achieve a long-term objective[40]. Unlike the motivational level, the number of actions cognition can monitor and execute at one time is limited, so that planning tends to pursue one task at a time[52-54]. Grammatical speech production is a classic example of a novel behaviour which requires planning: words must be produced in the proper serial order to have the intended meaning. Indeed, scripts were introduced largely to explain speech and text comprehension[34].

### *On scripts*

Determining what to do in many situations is a difficult task. Rigorously and systematically considering all the alternatives can sometimes take too long: for example, a predator may already have eaten you before you identify the optimal response. This kind of extended search has been mathematically proven an unrealistic model of intelligent behaviour[55]. This is because search is combinatorially explosive: more behaviours to consider or a more complex task to solve leads to an exponentially longer search. Though there is no doubt that animals do search for a best response in certain contexts (e.g. the deliberate choice of a gift), the search space must be tightly confined for an exhaustive search strategy to be successful. Since human behaviour is often complex, it is to be expected that many human behaviours are routinised. Rather than searching the entire range of possible combinations of behavioural elements, individuals can rely on previously stored memories which they can use as a foundation for action.

Sequences of behaviour which are often used successfully are 'chunked' together in memory by increasingly strong associations[56,57]. It then becomes possible for a single cue to activate the entire sequence[58]. This typically occurs automatically, thanks to non-conscious or implicit processing, which is assumed to be the normal, default mode of information processing, even in humans[59].

Memories of specific events and knowledge (i.e., semantic and episodic memory) are widely believed to be organised into schemas[60-62]. Schemas are a general way of representing knowledge which maps the relationships between elements of information. Scripts are a specific form of schema which differ from other schematic structures in two respects. First, the elements of scripts specify actions; second, the connections between actions in scripts are causal: the execution of some elements in the set depend on the prior execution of other elements[63]. Thus, calling up one part of a script from memory activates memory of the other, related bits of the sequence[64]. Further, scripts are executed as a chunk: initiating a script must be actively interrupted or will proceed through to the end. The execution of scripts thus results in an observable temporal ordering of actions.

The fundamental assumption of script-based behaviour is that the hierarchical structure of behaviour is mirrored in a hierarchical structure causing that behaviour: brain structures are hierarchical in nature, with higher-level elements controlling lower-order levels of task[36,65]. In effect, there is a parallelism between the mental representation of behaviour in memory and the organisation of the mechanisms that cause that behaviour: both structures of control and scripts are hierarchical in nature.

Thus, scripts are assumed to possess a hierarchical structure that determines the relationships among actions of varying levels and how they interconnect to constitute an event[34]. The levels of hierarchy in a script represent different levels of abstraction in conceptual space; they provide representations which brain structures can manipulate more efficiently than random elements of behaviour. Cognitive mechanisms can activate these schemas at a high level of abstraction (e.g., 'commence bedtime routine') and thus indirectly excite lower-level schemas in sequence, directly producing routine action sequences, but without needing to sustain attention and control itself, which is passed to autonomous, lower-level processes.

A famous example of a script is going to a restaurant[34]. At the top of this script's hierarchy is an element that summarises the whole event (*Figure 1*). Within a script, subscripts can be identified as 'scenes' and within scenes, 'vignettes' (i.e., sub-scenes and actions)[33]. One scene in the restaurant script is 'entering the restaurant'; a vignette occurs when the waiter presents the menu to the patron. Any script thus contains several elements that represent the characteristic grouping of actions. Each element has a central event, or 'main conceptualisation', which always takes place[33]. Examples in the restaurant script include ordering the meal or paying the bill.

Each element of a script has a default value that reflects a well-known, stereotypical situation; they reflect standardised aspects of repeated past experiences. Scripts thus 'fill in' default values for generic actions (i.e., default 'frames'). These defaults can leave out details, being abstracted from individual cases like a framework that needs to be elaborated to produce a response to a particular situation[33]. Scripts are thus a kind of knowledge structure which allow one to rapidly infer the normal values of things, and participate in events without much mental processing[34]. In this way, scripts significantly reduce search, and hence allow rapid responses to complex situations. They can be used to predict what others will do, to interpret what others have done, or to guide one's own behaviour.

Execution of a script is punctuated by check-points at which attention can intrude[42,66]. At these points, entry and exit conditions must be examined to determine whether one chunk of the script has been successfully completed and another chunk can be initiated (i.e., that which tends to follow because its entry conditions depend on the exit conditions of another chunk)[67]. Thus, each scene or action in the script results in situational constraints or conditions that determine whether the next action in a sequence can occur. For example, the preconditions for triggering the restaurant script are that the patron is hungry and has money; completing the script has the outcome conditions that the patron has less money and is not hungry, while the owner has more money. If these conditions are not met, a new scene or new action that is not prescribed in the original version of the script will be needed in order to complete the script (e.g., someone will need to pay the owner). Of course, attention processes are constantly on alert to determine if the script needs to be interrupted because some new situation has arisen since the script began executing; however, in the absence of such alerts, control remains at a relatively low level within each chunk.

The other components of a script are objects that perform various functions during the sequence of actions. These objects are divided into two groups: 'roles' and 'props'. Roles are the actors who take the actions. In the restaurant script, roles include the patron, cook, waiter, and owner. Props are the means that the roles use to accomplish actions; table, menu, food, check and money are typical props in the restaurant script. Roles and props can be filled in memory *a priori* by stereotypes. Thus a waiter can be stereotyped in people's minds as someone who is friendly and helpful, but may also, in another context, be a failed actor.

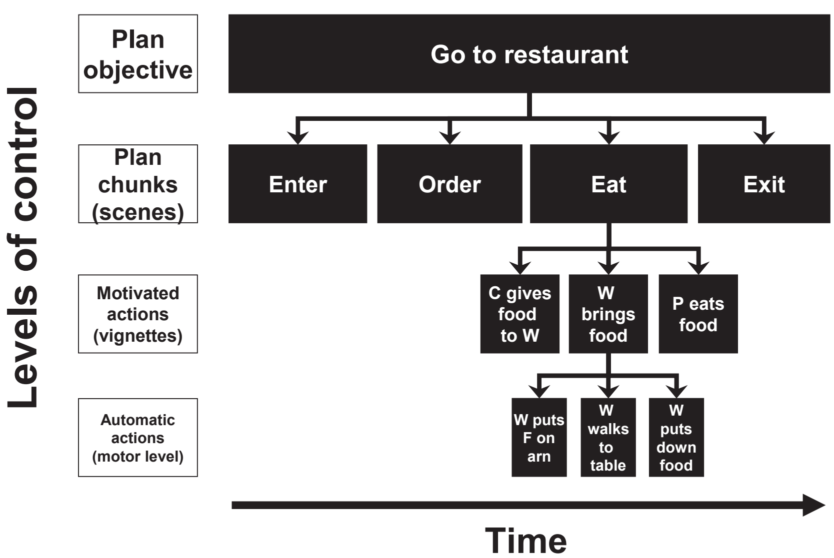


***Figure 1.*** The Restaurant Script

There are also several types of scripts. The restaurant script is 'situational' because it operates within a standardised context. Other scripts are called 'instrumental' because they do not involve other role-players, just props (e.g., lighting a cigarette). Tooth brushing is often an instrumental type of script because (at least once learned) it tends to be a private behaviour. 'Personal' scripts are those in which other role-players are reluctant or unwitting participants in the script's goals (e.g., chatting up the waiter), which make the situation a potentially hostile one[34]. For example, the personal scripts in a 'visit to the dentist' routine can be quite different for the two primary role-players: the dentist and the patient. From the dentist's perspective, the script can involve a patient who is recalcitrant; from the patient's perspective, the dentist can be seen ambivalently as someone who is providing a service, but also likely to cause pain.

Instead of processing all possible alternatives, script theory assumes that individuals rely on previously stored memories to direct attention and reduce cognitive effort while enhancing their comprehension of events. Scripts purportedly direct cognitive processing toward the appropriate inference when information is ambiguous or missing[33]. Hence, in a restaurant, if the waiter does not supply the bill, the customer will assume that he forgot to bring it, not that the meal is free. Reliance on routines enhances cognitive economy in the sense of maximising the availability of memory and consciousness for the execution of complex behaviour, because components of routines are delegated to the lowest necessary level of control, and chunking allows indefinitely long chains of activity to be controlled, despite limited working memory.

People appear to use scripts to help them understand and recall events. Subjects presented with a scrambled ordering of events that recur in everyday life can re-order them into proper sequence[68]. Similarly, people given information about an everyday event in random order have a tendency to recall these events in the order encapsulated by a script for that type of event[69]. Finally, when people are asked to list the components of everyday behaviours, many of the lists have common entries, suggesting regularities in the way semantic memories of events are encoded[69].

There is also evidence to support the assumption that memory of events is hierarchically organised. For example, scripts are assumed to exist in memory as chains of associations between component events[70,71]. This suggests that it should take longer to establish that two events further apart in a script belong together than two events which are more closely linked in time (and hence in memory). This 'gap size' effect has been demonstrated empirically[73].

## The Norman-Shallice-Cooper model

Scripts are used by brains to execute routine behaviour. Further discussion of routine behaviour in this paper will be based heavily on the Norman-Shallice-Cooper model, due to its explicit attention to the production of routine behaviour, although other three-level models are generally consistent with this perspective[40]. The basic idea of the NSC model (*Figure 2*) is that stimuli activate a perceptual system which categorises the stimulus, and feeds the categorisation to a set of algorithms which determine whether the object or situation detected has some significance. If so, a triggering condition activates a particular combination of basic action representations in the motivation network. The motivation network is a matrix of interconnected nodes representing either a goal or a partially ordered sequence of actions (i.e., a script). This network then activates the motor system to move the body in some way, constituting the behavioural response. The cognitive system (called the 'supervisory

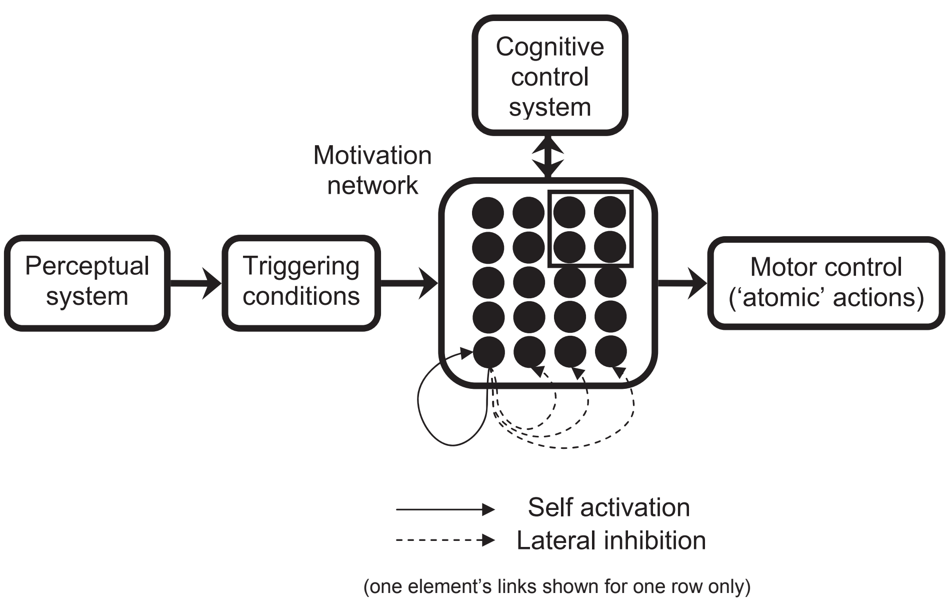


***Figure 2.*** The Norman-Shallice-Cooper Model

attention system' by Norman and Shallice) can introduce top-down control over this activity by modulating the activation of motivation network elements.

Information can flow through this model in three different ways, representing different levels of control over behavioural responses. Reactive behaviours occur when a one-to-one relationship has been established (by previous experience or explicit coding) between a particular triggering condition and goal (a node in the motivation network), and between that goal and a motor action. Thus, a particular perception strongly tends to lead directly to a particular behavioural response. The goal in this case can be satisfied by a particular 'atomic' action or motor command, and functions merely as an intermediary condition for activation of the appropriate motor response.

The interconnected matrix of nodes in the motivation network allows more complex behaviour to be built up. A primary function of motivational control is therefore to organise primitive behaviours into behaviour sequences. The motivation network is composed of nodes representing script elements which are connected to goal representations. Scripts are thus represented in the model as collections of script elements which tend to be highly interdependent and to be activated together (represented as a square cluster of black circles in *Figure 2*). Cooper and Shallice[41] add another network for representing the props necessary to enact scripts, together with triggering conditions for their activation, which further constrains the set of actions appropriate in a given circumstance. The script elements connected to a goal node represent distinct ways of achieving that goal, while the goal nodes linked to a script element are the set of end-states which must be reached to execute a script. Thus, the goal of preparing a cup of tea can be accomplished either by preparing instant tea or by brewing a pot of tea. Similarly, the script for preparing coffee can include a number of subgoals such as boiling water, putting tea into the water, pouring the tea into a cup, adding milk, and so on. These multiple, reciprocal linkages within the network mean that alternative routes can be found to satisfy a given goal, depending on current conditions.

Planned behaviour is enacted by the direct, sequential activation of script elements by the cognitive-level control system. In this case, the cognitive objective is directly imposed by the cognitive system on the motivational network, although feedback from the motivation network can tell the cognitive system how well progress toward the desired end-state is being achieved (i.e., which triggering conditions and interim goals have been satisfied). Cognition can also generate and implement new behavioural responses to effectively deal with novel situations, often via new combinations of script elements[57,73]. Linked script elements (i.e., scripts) thus form a compact and convenient representation of behavioural options for use by these higher level processes. In the NSC model, the cognitive layer is only activated by demand of the motivation network (e.g., when execution of the next scene of a script fails to be activated), so that expensive deliberation is triggered only when automation fails. Cognition has no direct access to motor control[41].

## Executing scripts

For a script to be executed, it must first be activated; then it must be selected from among competing scripts to determine behaviour. In the NSC model, scripts can be activated in two ways: by top-down instructions from cognitive level control or by environmental cues via the perceptual system[41,42] An interrupt signal from cognitive level control – possibly caused by a significant new stimulus in the environment – can cause a switch from one script to another, even before the current one has completed executing. On the other hand, features of the environment can function as cues that activate alternative behaviour production systems. For example, a predator and food might be present simultaneously, activating both fear and hunger reactions. If multiple scripts become activated simultaneously, they compete to control which behavioural option is enacted at a given time. In particular, scripts come into competition if they require the same cognitive or motor resources. Cognitive resources include special-purpose brain areas (e.g., a language module), while motor resources are those necessary to enact the behaviour (e.g., hands or feet). In the example above, one script will suggest approaching the food item, while the other will suggest fleeing the area – opposite kinds of uses of a person's legs.

Scripts compete to determine behaviour (a process called 'contention scheduling' by Norman and Shallice) in two ways: through lateral inhibition and self-activation[41,42]. Lateral inhibition involves one script element inhibiting the activation of another. Self-activation occurs when an activated schema increases its own degree of activation through positive feedback, thus sustaining its own activation against lateral inhibition. (See *Figure 2* where these feedback loops are represented for one script element's relationship to other elements in one row of the script network.) In effect, each element within a script feeds excitation back to itself as well as inhibiting its competitors in other scripts[41]. This means there is positive feedback among nodes within a scene, as well as inhibition of competing scripts, so that it becomes less likely that a competing schema will be initiated. These activation and competitive processes determine which script achieves the highest level of activation, and this script then determines what action the person undertakes.

Once selected, a script will remain in control of behaviour until a competing script's level of activation exceeds that of the selected one. Lateral inhibition and self-activation can lead to a bias for continued execution of the current script, often ensuring that it continues to the end once it has started. Highly active schemas thus tend to persist until all their constituent actions have been performed, and their exit conditions fulfilled.

Scripts which have been selected activate their component subscripts in a particular sequence. This sequence is determined by the triggering conditions which govern the circumstances under which particular script elements can be activated. Thus, pouring tea into a teacup can only occur if tea is already brewed in the pot. The strength of activation among script elements also determines what happens next; which script element is used to accomplish a sub-goal is determined by which is most appropriate given the circumstances, which is reflected in its degree of activation. The strengths of connection between script elements (basic actions) also change with experience, so that over time, positive feedback loops among script elements can strengthen the connections between them, making them more and more likely to produce the same sequence of behaviour on subsequent occasions. In this way, routines become increasingly engrained, as long as they are activated appropriately, and represent appropriate responses to a situation. Of course, these are also the tendencies which any effort at behaviour change must combat.

### *Changing routines*

We have argued that changing tooth brushing behaviour is a matter of modifying hygiene routines. In the NSC model, the cognitive system, through repetition, can 'train' the motivation system to perform new routines, after which it can normally complete routine behaviours autonomously and automatically[41]. Complex, well-established routines are thus controlled largely at the motivational level, although they remain under surveillance by the cognitive system (in the sense that a top-down interrupt may still occur). Brain imaging data confirms this suggestion from the model. When actions are based on memory (i.e., prior experience), control over movement derives from the corto-basal ganglia motor loop. The basal ganglia, in the limbic system, coordinates this movement, thanks to its projections to the premotor cortex, primary motor cortex, and supplementary motor areas. The highest level of control, the supplementary motor area, sends a plan of the intended movements to the lower levels of motor cortex, which execute the action[74]. This makes sense as complex behaviour, even when regularised, typically requires goal-direction to be successfully achieved, unlike reflexive reactions. Of course, at the moment of execution of a given script element, it is also true that there is a simple relationship between that element and the motor commands it activates, which make the moment-to-moment execution of routines automatic in nature, so that all levels of control are involved in some way in the production of routine behaviour.

Of course, 'routine' execution of scripts should be distinguished from processes designed to modify the execution of scripts – that is, from efforts to change behaviour. According to the NSC model, there are three ways to modify the way in which scripts are executed:

- Change the environment (and hence present novel stimuli to the perceptual system)
- Modify the motivational network (e.g., by adding or subtracting script elements or changing the weight of connection between elements)
- Modify the cognitive system.

Attempts to influence how behaviour is produced can thus be directed at any of these three different strategies. I will discuss each strategy in turn.

First, cues that trigger the desired script can be made more likely to appear in the environment of target individuals. This can involve modification of the environment itself (e.g., placement of a toothbrush in the bathroom) or communications which provide cues to the behaviour (e.g., posters with pictures of people tooth brushing). Because the script gets activated, its likelihood of being reinforced by feedback from the behaviour it produces is increased, which will increase the likelihood of the behaviour being repeated (if the feedback is positive). Alternatively, the execution of an existing script or scene can be inhibited by ensuring that its initial conditions are not satisfied, perhaps as a result of some body state (chewing gum after eating removes the sense of discomfort in the mouth that spurs tooth brushing) or a psychological state of the actor (e.g., a feeling of lassitude), or the lack of a necessary prop (the electric toothbrush has no power), or role (e.g., mother is not present to remind a child).

Incentives are environmental objects (i.e., resources like food or money) that increase the expected value of performing the desired behaviour (i.e., tooth brushing), to increase the degree of motivation. Incentives are which come to be associated with the desired behaviour. For example, children can be 'bribed' to brush their teeth by the promise to read them a story afterwards.

Like other forms of memory, the motivational network can be modified through experience and learning. First, new facts, beliefs or practices can be associated with a script. For example, an association can result in elements being added or subtracted to a script, or their execution being changed in some way (e.g., by reordering scenes)[36,64]. These associations can be learned rapidly, and hence new scripts formed after only a few trials. Existing knowledge can also be linked to some element of a script by experience or reflection, influencing how the script is processed next time around. For example, an individual might notice their yellowing teeth in the mirror one day and, remembering their previously white teeth, seek to recover this original condition by beginning to brush their teeth.

The skill-based aspects of scripts, however, require experience (i.e., behavioural practice) to modify; they can only be influenced indirectly. For example, through experience, the entry and exit conditions of a schema can be made more precise ('tuned') through feedback from situations for which the scripted behaviour is well-rewarded, so that subsequent activation and selection is only achieved in situations where this script is the most appropriate response[33]. Nevertheless, there should be significant overlap between the scripts for some event of different individuals because they are based on innate psychological structures, common learning mechanisms and environmental stimuli, particularly for the core features of each script[75].

At the cognitive level, logical arguments can induce an intention to engage in desired behaviour[75]. This will cause plans to be devised which increase the likelihood of the desired behaviour being performed[77-79]. Totally new scripts can be constructed as well. When faced with a novel situation, the cognitive layer of control can generate new scripts and monitor their implementation[73]. These new scripts are learned through wilful decision-making, which is likely to be conscious. Cognitive-level control can repeatedly apply this same strategy in a given situation.

However, modified scripts may not determine behaviour for some time, due to the need for high-level cognitive control to become convinced, through a body of evidence (i.e., experience), that the new response sequence is the most appropriate for a given situation[80]. This 'conservatism' of cognitive control is reasonable, given that execution of routine behaviours tends to become habitual (i.e., insensitive to rewards). So before cognition will hand over control to lower levels, other associations in the cortex must be overturned by proof that the world is regular enough to present the same situation again, and likely provide rewards, so that the brain does not have to pay attention to the details of execution (the alarm system being sufficient to flag up situations where a script might need changing). In such cases, when we find ourselves in a familiar environment, it is very likely that we will think and behave in a preordained way, without looking around for unexpected elements of the environment, or even responding to reductions in the level of reward for habitual action[81,82]. If a series of behaviours regularly proceeds in a particular sequence without interruption (i.e., gets triggered relatively often, and is seldom interrupted by the need to pursue other goals), they can be chunked in memory and executed with little cognitive effort and low-level attention (to ensure that no alarm is necessary)[42]. Routines which have been more often enacted, and with significant positive rewards (and no counter-acting punishments), will become more 'in-grained', and hence more difficult to modify. Thus, regularly rewarded daily routines in adults should be the most difficult to change.

## Modifying tooth brushing routines

Efforts to modify tooth brushing behaviour can make use of any of the strategies mentioned above. For example, providing financial rewards, social inducements (e.g., parental reprimands), rational arguments about the dangers of tooth loss, or leaving cues (such as a toothbrush) in a relevant place, can all increase the likelihood that a child will acquire the tooth brushing routine. In this section, however, I will concentrate on the ways tooth brushing behaviour can be changed which are suggested by the levels at which novel script elements can be introduced into a routine: at the level of an entire script, a script scene, or low-level script element. This perspective affords specific recommendations for behaviour change. Aspects of the different levels at which tooth brushing scripts can be modified are listed in *Table 1*.

People who do not currently brush their teeth at all must insert a complete tooth brushing script into their daily routines, presumably first into their breakfast routine, and then – to achieve the twice daily recommendation – into their bedtime routine as well. This typically requires a decision (conscious or not) to change their existing morning or bedtime routine script (see *Figure 3* for a graphical representation of the bedtime routine script). New skills in using a toothbrush must be learned, which requires practice to attain. To make the practice routine, a cue must be identified at the point in which the tooth brushing scene is to be inserted into the script, and the association of the cue with tooth brushing must be learned, so that the trigger becomes habitual. This requires significant cognitive control and a good deal of motivation, especially if existing routines are well-ingrained (i.e., during adulthood). Alternatively, it might require placing additional cues in the location where the morning routine is enacted. For example, putting a reminder on the refrigerator door. Through this decision-making or environment-modifying activity, individuals can find that the tooth brushing script acquires sufficiently high motivational priority that it gets enacted, overcoming the barriers that previously inhibited it.

Others may already know how to brush their teeth, and do so regularly in the morning, but now seek to conform to the twice daily norm. This requires inserting a scene into their nightly routine. However, in this case, a tooth brushing script is already available in memory; it must simply be inserted as a chunk into the bedtime routine. This requires learning a new association of a cue arising during the bedtime routine with tooth-brushing. This cue (e.g., the last trip to the bathroom before bed) will then tell the brain to instigate the tooth-brushing scene. Tooth-brushing skills (i.e., low-level motor actions such as wetting the brush) can be readily transferred to the new context, once the situation of being in the bathroom (or whatever is normal) has been initiated. Re-learning the basic skills is avoided by transfer to this new situation.

**Table 1** Types of routine change

| Current Practice | Routine Modification | Level Of Novel Script Element | CUE | Implications |
|---|---|---|---|---|
| Don't brush at all | Insert new script into existing routine | high | when finished eating breakfast | Requires significant motivation and new skill learning |
| Don't brush at night | Insert known script into existing routine | medium | when getting into bed | Requires chunk to be associated with new cue |
| Don't brush properly (e.g., not long enough) | Insert new automatism into existing chunk of routine | low | when putting brush into mouth | Can influence tooth-brushing components in multiple routines |

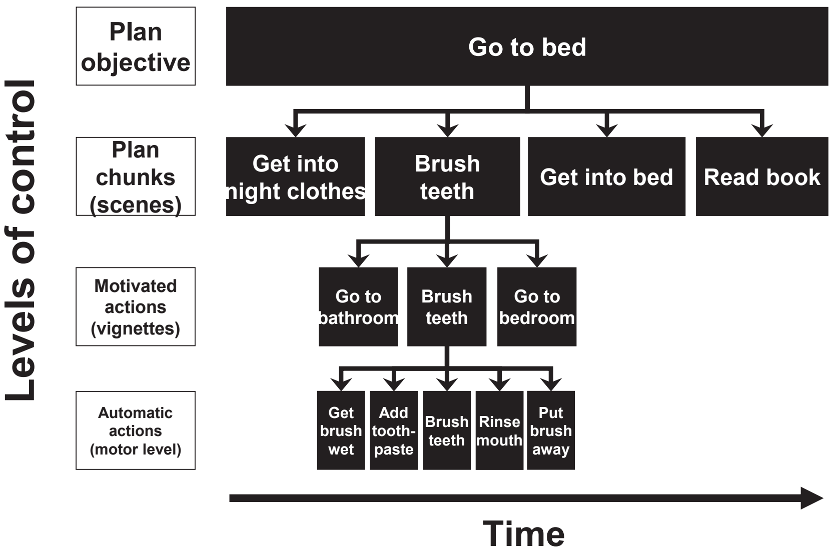


***Figure 3.*** The bedtime Tooth brushing Script

A third possibility is that a person already brushes twice daily, but does not perform the necessary brushing actions very well (at the lowest, motor level), or for a sufficient length of time, resulting in less-than-optimal plaque removal. Because changes to behaviour at this habitual level will not occur in the normal course of practice, it must be interrupted by a high-level alarm which signals the individual of the need to add a new level of execution to this on-going situation (no situational cues are likely to appear while brushing teeth; the amount of time for brushing is automatic, based on a subjective sense of 'enough'). The necessary alert must be provided by high-level cognitive control (i.e., a previous decision to remind oneself after beginning to brush that brushing will be continued for a longer period), or by some environmental cue (e.g., when opening the bathroom cabinet, seeing a reminder of some kind). For example, the 'Tooth Tunes' brand toothbrush (www.hasbro.com/toothtunes/) is an electric toothbrush which plays music for two minutes (if you keep brushing), helping people to brush for the recommended period of time, and hence is appropriate to the situation when people are already brushing twice a day, but are not doing so for long enough to have the maximum impact on plaque. Again, thanks to the modular nature of scripts, any improvements in the low-level performance of brushing achieved through such modifications can be implemented whenever the tooth brushing scene is enacted – in this case, both morning and night.

The discussion so far has assumed that tooth brushing is an 'instrumental' script that an individual is teaching themselves how to brush. However, in many cases, people learn to brush as children, under supervision of an adult, either in the home or at school. This suggests a different kind of tooth brushing script: one which is 'situational' in nature, as it involves multiple roles: the 'master' (e.g., parent) and 'apprentice' (e.g., child). In this case, the apprentice need not decide to toothbrush for themselves, but can be induced to repeat the necessary behaviours through supervision and instruction by the master. Alternatively, the apprentice can imitate the actions of the master while they toothbrush.

The roles played by an adult in these two types of the tooth brushing script are quite different. In the instrumental script, they are learners; in the situational one, masters attempting to train their apprentice. The motivations for playing these roles are also quite different: teaching oneself to brush requires a self-directed incentive, whereas for the master, the incentive to invest in teaching this skill is to nurture others. The self-model of 'being a good parent' may also involve passing on healthy habits to one's offspring. Such motivations may be enough to cause parents who do not yet know themselves how to brush to acquire the routine in order to be masters for their children, and thus begin a family tradition of tooth-brushing that proceeds from generation to generation. Recognising these different motivations might be important when attempting to get parents to teach their children tooth brushing routines.

Children playing the apprentice role in school also have somewhat different motivations than those playing the role at home: the desire to belong to the peer group can come into play in this context. If the members of the peer group are tooth-brushers, then this motivation becomes an incentive to brush; if peers are not, then the motivation to belong exerts psychological force against brushing. Children can also imitate their peers to acquire tooth brushing skills, rather than imitate the master, which may be more desirable at certain ages (e.g., when peer pressure exceeds the desire to please adults). Thus, intervening in schools might be recommended if children have not learned to brush teeth before becoming adolescents (when peer pressure is at its greatest), if the entire cohort can be induced to brush.

## Empirical support for tooth brushing behaviour change as routine modification

The literature on dental interventions supports the model of routine modification described here. In particular, it argues that in learning new routines, cognitive control has an important role to play, either by triggering an alarm (not to continue with low-level control), or to explicitly learn a new association, or to plan action in advance. Cognitive self-management of oral hygiene practices, primarily through the creation of explicit plans or so-called 'implementation intentions'[76], should thus be the preferred way to induce self-care. For example, in a sample of Swedish adults, a written commitment to increase self-care led to reported improvements in flossing, reduced plaque and reduced periodontal pockets at a three month follow-up[83]. Similarly, a PRO-SELF programme (designed to enhance self-management of activities for a variety of ailments, from cancer to pain management) delivered to HIV-seropositive patients led to weak improvements in oral hygiene and reduced candidiasis at six months post intervention[84]. Further, a one-minute intervention designed to teach people how to form a concrete plan of where, when, and how to floss also successfully increased reported rates of flossing at a two-month follow-up[85]. Thus, getting people to make conscious decisions about the need to brush their teeth can have a positive impact on the creation of new routines.

In forming routines, self-regulation should increase the ability to persist with self-care over purely motivational criteria. This is because motivation can waver, and is specific to particular situations which might not always be present when teeth should be brushed[86]. As expected, interventions based on increasing people's ability to manage their own behaviour do better than purely motivational ones – that is, there appears to be an added influence of volitional over motivational factors in creating or maintaining oral hygiene practices. For example, positive social reinforcement (praise – a motivational technique) reduces plaque in periodontal patients, but providing patients with tools for self-monitoring of their behaviour further reduces plaque[87]. Forming an implementation intention (i.e., planning) also increases reported use of dental floss over and above the influence of motivational factors such as risk perception, outcome expectancies, self-efficacy and intentions[88]. Finally, in a sample of diabetic patients (who are often subject to periodontal disease), self-efficacy (a construct aligned with competence, not motivation) was more strongly correlated with oral health (number of caries lesions and periodontal pockets) than motivational variables (e.g., intention to brush, locus of control or self-esteem)[89].

Further, self-management does not necessarily require new knowledge about the health consequences of oral hygiene or instructions about how to brush teeth; these are probably already present in many people, but have not worked to cause tooth brushing routines to form due to a lack of motivation. Hence, interventions which include motivational components work better than purely educational ones. For example, an intervention designed to increase motivation through motivational therapy increased self-efficacy for flossing significantly more than an intervention which only provided knowledge about the causes and prevention of dental disease[90]. An intervention based in self-determination theory[91] also led to increased perceived competence and motivation for self-care in a sample of patients visiting a dental hygienist for advice and therapy. These psychological changes in turn produced increased brushing and flossing, decreased plaque and hence decreased gingivitis[92]. However, interventions designed to increase motivation directly (i.e., without appeal to the creation of routines) have not proven as successful. In particular, motivational counselling targeted at adolescent Finnish school children was ineffective in improving oral hygiene habits, but this may be because it was based on giving normative (i.e., educational) advice[93].

This evidence is highly consistent with our model of routine initiation and modification. First, education is not necessarily relevant. Although knowing the health benefits of dental care can help proper practice of tooth brushing (e.g., by increasing the length of time that people brush), it is also necessary to give people an inducement to begin the practice of new behaviours. Second, motivation is not enough (although better than just information): learning or modifying routines requires cognitive effort. Most routine behaviours are not executed to achieve rewards; they are not motivated behaviours. Instead, they must be learned using cognitive control, so that normal practice can later be executed using low-level, cue-based automatic control.

Finally, there is another source of support for the approach developed here. Advertisements can be seen as commercial interventions to induce desired behaviours, such as buying products on offer. The history of advertising toothbrushes in the United States (where documentation is best) therefore provides an interesting case study that mirrors the intervention strategies suggested by this model of tooth brushing as a routine practice[94]. When tooth brushing was still a relatively unknown practice, in the last decade of the 19$^{th}$ century in the US, advertisements had tag-lines about 'how to brush' and 'the best dentists recommend tooth brushing'. These early advertisements promoted a company's toothbrush but also instructed the public on proper dental hygiene. However, once this basic knowledge had been transmitted and widely learned, advertising turned to fear-appeals. Tooth brushing was announced to fight tooth decay due to germs in the mouth, which can be prevented by self-care. This strategy was necessary to convince those adults not motivated simply by awareness of the option to brush their teeth. Then, in the 1920s, advertisers turned to various fundamental motivations: the sexual attractiveness of having clean white teeth (vanity appeared often in hygiene advertisements), or the idea that high status individuals (e.g., wealthy businessmen) commonly practiced this 'modern' habit. (http://www.historic-northampton.org/601081/601508/802/)

As they were relying on these stronger inducements to adults, advertisers also turned to the suggestion that being a good mother requiring care for children's dental hygiene. Advertisements for specialised children's toothbrushes made their appeal not to the children, but to parents (http://www.historic-northampton.org/601081/601508/802/). This suggests that advertisers also knew that children are not intrinsically motivated to learn tooth brushing, but are guided into this practice by their parents. Finally, more recently, some advertisements have directly appealed to children with engaging kinds of toothpaste and colourful, easy-to-hold toothbrushes with soft bristles.

Thus, advertisers have followed the same strategy that, over time, has been suggested here: First, motivate adults (particularly mothers) to take up the practice of brushing their teeth; then, once they have acquired the routine, induce them to pass it on to their children; and finally, address children themselves, perhaps at school, with reasons to brush their teeth. As might be expected of campaigns based on a good understanding of consumers, these marketing interventions recognise the routine nature of tooth brushing, and adopt means designed to teach people how to create these routines for themselves, in a family context (particularly mothers and their offspring).

The order in which the strategies were used makes sense from the point of view of promoting an innovation to spread through a population[95]. Early, educational appeals probably were enough to convince early adopters, who already had the motivation to brush, and a love of new technology, to try the practice. Advertisements based on fear and other emotions such as status admonished adults who were laggards in the adoption of this innovation to take it up. Finally, children were targeted in an attempt to reach the niche market of youngsters who had not been influenced by their parents to become toothbrushers.

## Conclusion

Getting individuals to brush their teeth, together with regular visits to a dental professional for reinforcement, appears to be the most effective method for preventing dental diseases[15]. However, it has proven difficult to motivate those who currently are not regular toothbrushers into these practices. In this paper, I have argued that tooth-brushing is a routine behaviour. This claim is supported by a variety of evidence. From a public health perspective, the implication of tooth brushing being routine is that interventions should seek to instigate these routine practices within families which then train their offspring to brush their teeth. Assuming that more families persist with such traditions than drop them, the number of family traditions can be made to increase, turning a larger proportion of the population into toothbrushers. This requires an emphasis on motivating adults to induce the practice in those they care for, children to learn in a peer-assisted context, and (if necessary) adults learning to brush themselves, so as to be able to serve as models of good custom, and to train those in their charge.

From the perspective of professional practice, it is interesting to note that visiting a dentist can itself be seen as a script; in fact, it was one of Shank and Abelson's original example[34,96]. Changing elements of this script (e.g., the stereotypical view of a visit to the dentist as something which is painful would help get people to visit dentists more often and hence be exposed to tooth-brushing messages and advice[97,98].

I hope to have shown here the utility of treating tooth-brushing as routinised behaviour, especially when it comes to attempts to modify that behaviour. However, it remains to be shown empirically that interventions which explicitly treat tooth brushing as routine are more effective than those which do not. I hope that this discussion will stimulate such studies.

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