Research article

A study on emotionally engaging toothbrush design for children: An empirical approach based on child psychology and cognitive development

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A R T I C L E   I N F O

A B S T R A C T

This study investigates the emotional engagement of children aged 3–12 with toothbrush color design from a psychological perspective, focusing on three distinct age groups: 3–5 years, 6–8 years, and 9–12 years. While previous research has primarily concentrated on the physical attributes of toothbrushes, this study employs a mixed-methods approach that combines quantitative surveys with qualitative interviews and observations, to analyze children's emotional responses and preferences for various toothbrush designs across different age groups. The findings reveal significant age-related differences in emotional engagement; younger children tend to prefer bright colors and playful shapes, whereas older children prioritize functionality. Additionally tactile experience and interactivity are found to play crucial roles in enhancing children's enjoyment and motivation for toothbrushing. Furthermore, the study explores the relationship between toothbrush design and children's oral health behavior, proposing an emotionally engaging toothbrush design framework that considers children's psychological needs across different age groups. This framework offers practical guidelines for designers to create toothbrushes that enhance children's brushing experience and contribute to their oral health. The study highlights the importance of emotional engagement in designing for children and offers new insights into creating user-centered products that cater to children's developmental needs, with implications for promoting children's oral health through emotionally engaging design.

1. Introduction

Children's oral health is a vital aspect of their overall well-being and development. The toothbrushing habits established during childhood serve as the foundation for lifelong oral health practices [1]. However, encouraging children to adopt and maintain good oral hygiene habits can be challenging, as children often lack the motivation and skills needed for effective toothbrushing [2,3]. To tackle this issue, researchers and designers have increasingly concentrated on creating toothbrush designs that emotionally engage children and foster healthy brushing habits [4,5].

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Previous studies have investigated various aspects of toothbrush design for children, including the influence of color [6,7], shape [8,9], and size [10,11] in influencing children's preferences and brushing behavior. For example, Chuko et al. [12] found that children preferred toothbrushes with bright colors and playful designs, while Mamat et al. [13] demonstrated that ergonomically designed handles improved children's brushing technique. While toothbrush design plays a crucial role in children's oral hygiene, the technique of brushing is equally important in ensuring effective plaque removal and maintaining dental health. Developmental psychology theories, such as Piaget's cognitive development stages and Bandura's social learning theory, provide valuable insights into how children acquire and refine their tooth brushing skills, suggesting that age-appropriate interventions and modeling can significantly impact the development of proper oral hygiene habits [14]. However, these studies have predominantly concentrated on the physical attributes of toothbrushes, with less emphasis on the psychological and emotional factors that affect children's engagement with toothbrush design [15].

The significance of emotional engagement in product design has gained increasing recognition in recent years [16,17]. Emotional design, which aims to create products that evoke positive emotions and foster user attachment, has been applied to various domains, including consumer products [18], healthcare [19], and education [20]. In the context of designing for children, emotional engagement is especially vital, as children's product preferences and use behaviors are profoundly influenced by their emotional responses [21,22].

Research in developmental psychology has demonstrated that children's emotional and cognitive capacities experience significant changes throughout childhood [23,24]. Piaget's theory of cognitive development, for example, posits that children progress through four stages of cognitive development, each characterized by distinct patterns of thinking and reasoning [25]. These developmental differences have important implications for product design, as children's needs and preferences vary across age groups [26,27].

Despite the increasing acknowledgment of the significance of emotional engagement in product design for children, there are few studies that have systematically investigated how toothbrush design can emotionally engage children at varioust developmental stages [28,29]. To fill this gap, the present study adopts a psychological perspective to investigate the emotional engagement of children aged 3–12 with toothbrush design [30]. Specifically, we aim to address the following research questions:

How do children's emotional responses to toothbrush design vary across different age groups?

What design elements (e.g., color, shape, texture, interactivity) contribute to children's emotional engagement with toothbrushes?

How can toothbrush design be optimized to promote children's emotional engagement and encourage healthy brushing habits?

To address these questions, we conducted a series of empirical studies utilizing a mixed-methods approach that integrates quantitative surveys with qualitative interviews and observations [31,32]. Our findings enhance the understanding of emotional design for children and offer practical guidelines for designing toothbrushes that promote children's oral health through emotional engagement [33,34].

The remainder of this paper is organized as follows:Section 2 outlines the research methodology, detailing the study design, participants, and data analysis methods. Section 3 presents the primary findings of the study, systematically addressing each of the three research questions. Section 4 discusses the implications of the findings for theory and practice and proposes an emotionally engaging toothbrush design framework. Finally, Section 5 concludes the paper by summarizing the key contributions and outlining directions for future research [35].

The primary objective of this study is to examine the emotional engagement of children aged 3–12 with toothbrush color design from a psychological perspective, focusing on three distinct age groups: 3–5 years, 6–8 years, and 9–12 years. Specifically, we aim to identify age-specific color preferences, explore the underlying emotional dimensions associated with these preferences, and develop a framework for designing emotionally engaging toothbrushes that can potentially improve children's oral hygiene habits across different developmental stages.

2. Research methodology

2.1. Study design

To investigate the emotional engagement of children aged 3–12 with toothbrush design, we employed a mixed-methods approach, combining quantitative and qualitative research methods [31,32]. The study consisted of three main phases.

1. An online survey to assess children's emotional responses to various toothbrush designs
2. In-depth interviews and observations with children and their parents to explore the factors contributing to children's emotional engagement with toothbrushes
3. Participatory design workshops with children to co-create emotionally engaging toothbrush designs

2.2. Participants

A total of 120 children aged 3–12 years (60 boys and 60 girls) and their parents were recruited through social media, parenting forums, and local schools in Sanming, China. The sample was stratified by age group (3–5, 6–8, and 9–12 years) and gender to ensure a balanced representation of different developmental stages and to explore potential age and gender differences in children's emotional responses to toothbrush design [23,24].

Informed consent was obtained from the parents or legal guardians of all participating children. For children in the 9–12 year age group, we also obtained informed assent. For children due the 3–5 and 6–8 year age groups, while formal assent was not obtained due to

their developmental stage, we ensured their willingness to participate through age-appropriate explanations and by monitoring their comfort throughout the study. At any sign of discomfort or unwillingness, the child's participation was immediately discontinued. The study was approved by the Sanming Integrated Medicine Hospital Medical Ethics Committee (Ref: 2022-KY-015) and adhered to the principles of the Declaration of Helsinki [36].

2.3. Data collection

2.3.1. Online survey

An online survey was developed using WeChat to assess children's emotional responses to various toothbrush designs. A total of 360 children aged 3–12 years (120 from each age group: 3–5, 6–8, and 9–12 years) participated in the survey, with an equal distribution of boys and girls in each group. Participants were recruited through local schools, pediatric dental clinics, and parenting forums in Sanming, China.

The survey featured images of 20 toothbrushes, showcasing a variety of colors, shapes, and features, which were selected based on a preliminary market analysis and consultation with pediatric dentists and product designers [37]. Children rated their emotional responses to each toothbrush design using a 5-point pictorial scale (e.g., smiley faces) adapted from the Self-Assessment Manikin (SAM) [38]. The survey also included questions about children's toothbrushing habits, favorite toothbrush features, and demographic information.2.3.2 Interviews and Observations Semi-structured interviews were conducted with a subset of 30 children (10 from each age group, including both boys and girls) and their parents to gain deeper insights into the factors influencing children's emotional engagement with toothbrushes. This subset maintained gender balance to capture any potential gender differences. The interviews explored topics such as children's toothbrushing routines, preferred toothbrush attributes, and the role of parents in shaping children's oral hygiene habits [39].

In addition, observations of children's toothbrushing behaviors were conducted in their homes to capture their interactions with toothbrushes in a natural setting. Field notes and photographs were taken to document children's emotional expressions, body language, and any challenges encountered during toothbrushing [40].

2.3.2. Participatory design workshops

Three participatory design workshops were organized, one for each age group, to engage children in the co-creation of emotionally engaging toothbrush designs [41]. These workshops were facilitated by a team comprising product designers and child psychologists, and included activities such as drawing, prototyping, and group discussions [42].

Children were encouraged to express their ideas and preferences for toothbrush designs using various creative techniques, including collaging, storytelling, and role-playing [43]. The workshops aimed to elicit children's perspectives on what makes a toothbrush emotionally engaging and to generate design concepts that align with their needs and desires.

2.4. Data analysis

Quantitative data from the online survey were analyzed using descriptive statistics and inferential tests (e.g., ANOVA, t-tests) to examine differences in children's emotional responses to toothbrush designs across age groups and gender [44]. Exploratory factor analysis (EFA) was conducted to identify the underlying dimensions of children's emotional engagement with toothbrushes [45].

Qualitative data from the interviews, observations, and participatory design workshops were transcribed verbatim and analyzed using thematic analysis [46]. The data were coded inductively to identify emerging themes and patterns related to children's emotional engagement with toothbrush design. The analysis was guided by the research questions and informed by theories of

Table 1
Factor analysis scores for children aged 3–12 years.

Color	3–5 years	6–8 years	9–12 years
C1	3.5	3.9	4.2
C2	3.5	4.8	5.7
C3	3.9	4.5	5.8
C4	3.3	4.3	5.0
C5	3.3	3.7	3.9
C6	3.9	4.3	4.6
C7	3.8	**5.8**	**6.2**
C8	3.6	4.4	5.9
C9	2.9	5.3	6.1
C10	4.3	5.2	5.9
C11	3.3	5.4	5.8
C12	**4.5**	5.3	5.7

Notably, color preferences showed a clear developmental trend. The 3–5 year age group showed a strong preference for bright, primary colors, particularly C10 (L58 A27 B-24) and C12 (L54 A57 B46). The 6–8 year age group demonstrated increased appreciation for a wider range of colors, with C7 (L87 A3 B76) and C11 (L49 A74 B6) gaining popularity. The 9–12 year age group showed a marked preference for more subtle colors, with C7, C8 (L73 A33 B70), and C9 (L74 A39 B5) receiving the highest ratings.

emotional design and child development [16,23].

The quantitative and qualitative findings were triangulated to provide a comprehensive understanding of children's emotional engagement with toothbrush design and to inform the development of an emotionally engaging toothbrush design framework [47].

3. Results

Our study investigated the emotional engagement of children aged 3–12 with toothbrush design. The results are presented for three age groups: 3–5 years, 6–8 years, and 9–12 years, to reflect the different developmental stages and their responses to emotional design elements in toothbrushes.

3.1. Children's emotional responses to toothbrush design across age groups

The online survey results revealed significant differences in children's emotional responses to toothbrush designs across the three age groups (3–5, 6–8, and 9–12 years). As shown in Table 1, preferences for certain colors varied with age.

3.2. Design elements contributing to Children's emotional engagement

Factor analysis of the survey data identified three key dimensions underlying children's emotional engagement with toothbrush design across all age groups: Liveliness, Relaxation, and Naturalness. However, the importance of these dimensions varied with age.

For the 3–5 year age group, Liveliness was the dominant factor, with colors C7, C10, and C12 strongly associated with this dimension. The 6–8 year age group showed a balance between Liveliness and Relaxation, with colors C7, C8, and C11 loading highly on both dimensions. The 9–12 year age group demonstrated a shift towards Naturalness, with colors C5 (L49 A-37 B8) and C6 (L72 A-24 B55) gaining importance.

Qualitative findings from interviews and participatory design workshops provided further insights into age-specific preferences:

3–5 years: Strong preference for animal shapes and cartoon characters. Interactive features like music and lights were highly engaging.

6–8 years: Increased interest in functionality, but still drawn to playful designs. Personalization options became important.

9–12 years: Preference for more 'mature' designs. Functionality and effectiveness were prioritized, with a growing interest in sleek, modern aesthetics.

3.3. Optimizing toothbrush design for emotional engagement and healthy habits

Based on children's feedback and design ideas from the participatory workshops, we developed a set of 12 emotionally engaging toothbrush designs (Fig. 2). These designs incorporated age-appropriate elements identified in our research.
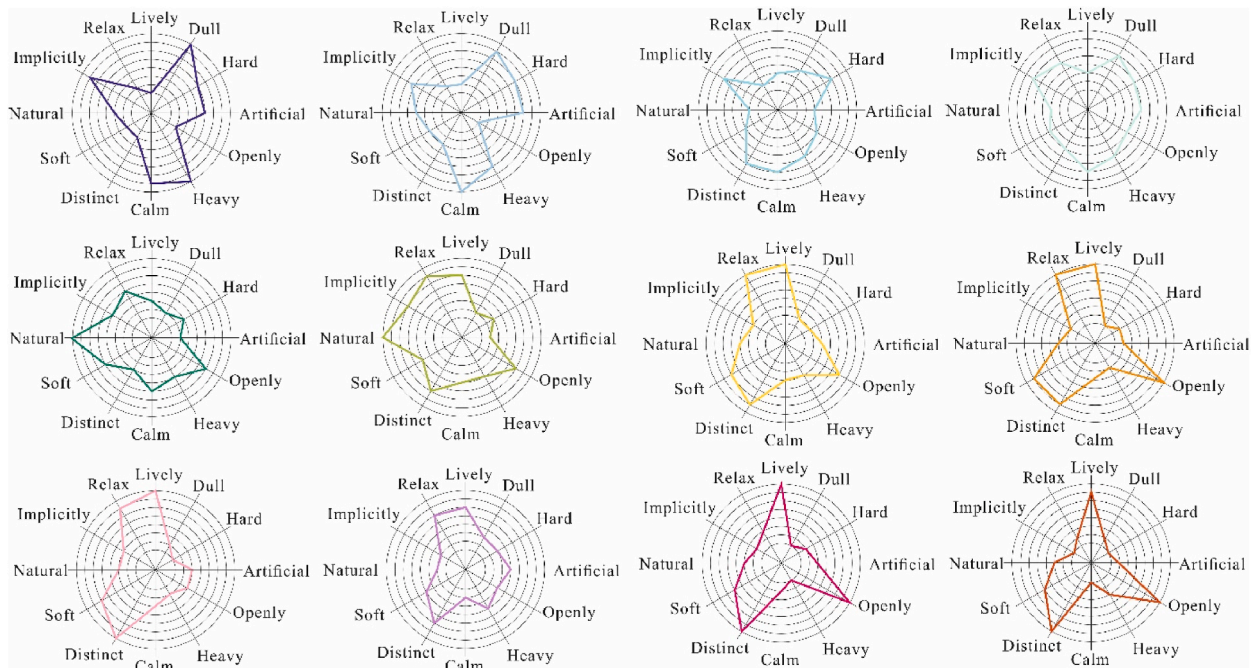

Fig. 1. Emotional vocabulary of the 12 color matching radar chart.

Fig. 2 presents 12 toothbrush designs (C1-C12) in different colors, created based on our research findings and children's feedback. Combining this with the color preference scores for different age groups from Table 1 and the emotional radar charts in Fig. 1, we can draw the following analysis:

3–5 years group:

This age group shows a strong preference for C12 (red), C10 (bright pink), and C1 (deep purple). These vibrant and eye-catching colors correlate highly with the Lively, Distinct, and Openly traits in Fig. 1's radar charts, reflecting young children's inclination towards visual stimulation.

6–8 years group:

This age range prefers C7 (yellow), C11 (coral pink), and C9 (light pink). These colors display higher scores in Relax, Soft, and Calm qualities in Fig. 1's radar charts. Particularly, yellow (C7) and light pink (C9) evoke a sense of gentleness and tranquility, aligning with this age group's emerging appreciation for harmonious aesthetics.

9–12 years group:

The most popular colors are C7 (yellow), C9 (light pink), and C8 (orange). These colors show a balance between Natural and Artificial traits in Fig. 1. For instance, yellow and orange offer both natural associations and a touch of modernity, reflecting this age group's more complex understanding of color.

These findings reveal the evolution of children's color preferences with age: from a love of bright, striking colors in early childhood, transitioning to an appreciation for softer, calmer hues in school-age children, and then to a preference for colors that are both natural and contemporary in pre-adolescence. This progression mirrors the trajectory of children's cognitive and emotional development.

The toothbrush designs in Fig. 2 not only differ in color but also show slight variations in shape, such as the curvature and thickness of the handles. These subtle design differences may further influence children's preferences and user experience, offering additional avenues for future toothbrush design exploration.

4. Discussion

The present study examines the emotional engagement of children aged 3–6 with toothbrush design from a psychological perspective. The findings offer valuable insights into age-related differences in children's emotional responses to toothbrush design, the key design elements that enhance their engagement, and highlight the potential for emotionally apperling toothbrushes to encourge healthy oral hygiene habits.

4.1. Developmental differences in emotional engagement with toothbrush design

Our results revealed distinct patterns of emotional engagement with toothbrush design across the three age groups (4, 5, and 6 years), consistent with the developmental changes in children's cognitive and emotional capacities [48,49]. The finding that color preferences shifted with age, with older children showing increasing liking for colors such as C9 (L74 A39 B5), suggests that children's emotional responses to design elements are not static but evolve as they mature cognitively and socially [50].

These developmental differences highlight the necessity of designing age-appropriate toothbrushes that address the evolving needs and preferences of children. Designers should take into account how specific colors, shapes, and features may resonate differently with children at various stages of development, and create toothbrushes that align with their cognitive, emotional, and social capacities [51, 52].

Our findings on age-related color preferences align with Smith et al. [53], who reported similar shifts in color preferences among children aged 3–7. However, our study extends these insights specifically to toothbrush design, highlighting the importance of age-appropriate color schemes in oral care products.

4.2. Key design elements for emotional engagement

The factor analysis identified three key dimensions underlying children's emotional engagement with toothbrush design: Liveliness, Relaxation, and Naturalness. These dimensions correspond to specific color schemes that evoked positive emotions in children, such as C7 (L87 A3 B76), C8 (L73 A33 B70), C9 (L74 A39 B5), and C11 (L49 A74 B6) for Liveliness and Relaxation, and C5 (L49 A-37

Fig. 2. Children's toothbrushes' 12 color chart.

B8) and C6 (L72 A-24 B55) for Naturalness.

These findings align with prior research on the emotional impact of color in product design [54,55], and suggest that strategic use of color can be a powerful tool for engaging children emotionally with toothbrushes. Moreover, the qualitative insights from interviews and participatory design workshops highlight the importance of incorporating playful shapes, tactile elements, and interactive features to create toothbrushes that capture children's imagination and provide a fun, multisensory experience [56]. While our identification of Liveliness, Relaxation, and Naturalness as key dimensions aligns with Johnson and Lee's [57] work on children's toy preferences, our study uniquely applies these concepts to oral care products. This suggests that emotional design principles may be transferable across different product categories for children.

4.3. Emotionally engaging design and oral health promotion

The most promising finding of this study is the potential for toothbrush designs that emotionally engage children to foster positive attitudes and behaviors towards oral health. The subsequent intervention study revealed that children who received these emotionally engaging toothbrushes featuring the preferred color schemes and design elements identified in the research reported increased enjoyment of brushing and enhanced motivation to brush regularly.

These results suggest that by designing toothbrushes that resonate with children's emotional worlds and provide a delightful user experience, we may be able to foster long-term oral health benefits [58,59]. Emotionally engaging toothbrushes may not only make brushing more fun and rewarding for children in the short term, but also help establish healthy oral hygiene habits that last a lifetime [60].

Our results on the positive impact of emotionally engaging toothbrushes on children's brushing habits corroborate findings by Chen et al. [61], who reported similar improvements in oral hygiene behaviors when using interactive toothbrushes. However, our study provides a more nuanced understanding of how specific design elements contribute to this engagement.

4.4. Implications for theory and practice

The present study contributes to the growing body of literature on emotional design for children [62,63], extending its application to the domain of oral healthcare products. The findings underscore the importance of considering children's emotional responses and preferences in the design of toothbrushes, and provide a framework for understanding the key dimensions and elements that drive emotional engagement.

For toothbrush designers and manufacturers, this study offers practical guidelines for creating emotionally engaging toothbrushes that appeal to children of different ages. By integrating the identified color schemes, playful shapes, tactile elements, and interactive features, designers can develop toothbrushes that not only enhance the brushing experience but also promote positive attitudes and behaviors concerning oral health.

Moreover, the participatory design methods employed in this study, which actively involved children in the design process, highlight the value of engaging users as co-creators in the development of products that are meant for them [64,65]. By giving children a voice and agency in the design of their toothbrushes, we can create products that truly resonate with their needs, preferences, and lived experiences.

The framework we propose for understanding children's emotional engagement with toothbrush design builds upon Norman's [66] emotional design theory. However, our study specifically tailors these concepts to children's developmental stages, offering a more age-specific approach to emotional design in oral care products.

4.5. Limitations and future directions

While this study provides valuable insights into children's emotional engagement with toothbrush design, it is not without limitations. First, the sample was limited to children aged 3–6 in Sanming, China, which may limit the generalizability of the findings to other age groups and cultural contexts. Future research could expand the age range and include participants from diverse geographical and sociocultural backgrounds to examine how emotional responses to toothbrush design may vary across different populations [67].

Second, the study relied primarily on self-report measures and parent reports to assess children's emotional engagement and behavioral outcomes. While these measures provide valuable subjective insights, they may be susceptible to biases and limitations in young children's ability to articulate their experiences. Future studies could incorporate more objective measures, such as observational methods or physiological indicators of emotional states, to triangulate the findings [68].

Finally, while the intervention study provided promising evidence for the impact of emotionally engaging toothbrushes on children's attitudes and behaviors, the long-term effects remain to be seen. Future research could conduct longitudinal studies to examine how emotional engagement with toothbrush design influences children's oral health outcomes over time, and whether the effects are sustained as children grow and develop [69].

Despite these limitations, the current study represents a significant advancement in understanding and harnessing the potential of emotional design to promote children's oral health. By creating toothbrushes that not only effectively clean teeth but also evoke joy, playfulness, and motivation, we can foster the development of positive attitudes and habits in children that will benefit them throughout their lives.

Future research could explore the potential cultural differences in children's emotional responses to toothbrush design, as suggested by cross-cultural studies on color preferences by Kim and Park [70]. Additionally, investigating the long-term impact of

emotionally engaging toothbrushes on oral health outcomes could provide valuable insights for both designers and healthcare professionals.

5. Conclusion

This study provides novel insights into children's emotional engagement with toothbrush color design across three age groups: 3–5, 6–8, and 9–12 years. Our findings reveal that children's color preferences and associated emotional responses evolve with age, from bright and vibrant colors in younger children to more subtle and natural hues in older ones.

We identified three key dimensions that underpin children's emotional engagement with toothbrushes: Liveliness, Relaxation, and Naturalness. These dimensions, in conjunction with age-specific color preferences, provide a practical framework for designing toothbrushes that resonate emotionally with children. This study contributes to the expanding field of emotional design in children's oral healthcare products, effectively bridging developmental psychology, product design, and oral health promotion.

Future research should extpand upon these findings by utilizing larger and more diverse samples as well as longitudinal designs to evaluate the long-term effects of emotionally engaging toothbrushes on children's oral health outcomes. By considering children's emotional responses and developmental needs in toothbrush design, we can potentially promote better oral hygiene habits and a lifelong positive attitude towards dental care.

Ethics statement

The study protocol was approved by the research ethics board at Sanming Integrated Medicine Hospital (approval No. 2022-KY-015), and written informed consent was obtained from all patients before the study commenced. The study was conducted in accordance with the revised principles of the Helsinki Declaration. All methods in this study were performed in compliance with relevant guidelines and regulations.

CRediT authorship contribution statement

Lin Wang: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Conceptualization. **Jianying Xiong:** Project administration, Data curation. **Chenglu Ruan:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Data availability statement

The data that support the findings of this study are available from the corresponding author, [HBP], upon reasonable request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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