






## ORIGINAL ARTICLE

# Understanding children's attention to traumatic dental injuries using eye-tracking

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## Abstract

**Background/Aim:** Traumatic dental injuries (TDIs) in the primary dentition may result in tooth discolouration and fractures. The aim of this child-centred study was to explore the differences between preschool children's eye movement patterns and visual attention to typical outcomes following TDIs to primary teeth.

**Materials and Methods:** An eye-tracker recorded 155 healthy preschool children's eye movements when they viewed clinical images of healthy teeth, tooth fractures and discolourations. The visual search pattern was analysed using the eye movement analysis with the Hidden Markov Models (EMHMM) approach and preference for the various regions of interest (ROIs).

**Results:** Two different eye movement patterns (distributed and selective) were identified ( $p < .05$ ). Children with the distributed pattern shifted their fixations between the presented images, while those with the selective pattern remained focused on the same image they first saw.

**Conclusions:** Preschool children noticed teeth. However, most of them did not have an attentional bias, implying that they did not interpret these TDI outcomes negatively. Only a few children avoided looking at images with TDIs indicating a potential negative impact. The EMHMM approach is appropriate for assessing inter-individual differences in children's visual attention to TDI outcomes.

## KEYWORDS

children, eye-tracking, primary teeth, tooth fracture and discolouration

## 1 | INTRODUCTION

Traumatic dental injuries (TDI) affect around one-third of preschool children.<sup>1</sup> Falls have been reported as the most common aetiology of trauma in the primary dentition at 76%, with 98% of affected teeth being the maxillary central incisors.<sup>2</sup> Typical outcomes of TDIs in the primary dentition include fractures and discolouration, which may be discerning to the eye of the beholder.

The psychosocial impacts of TDIs are unique to each individual and are based on the resulting consequences. For example, Goncalves et al.<sup>3</sup> in 2017 stated that approximately 15% of children in their study, aged 2 to 5 years, had an aesthetic impairment following TDIs, as reported by their parents, with tooth discolouration having the most significant aesthetic impact. Cortes et al.<sup>4</sup> in 2002 reported that 12- to 14-year-old children with untreated TDI were 20 times more likely to report a negative effect on their daily lives

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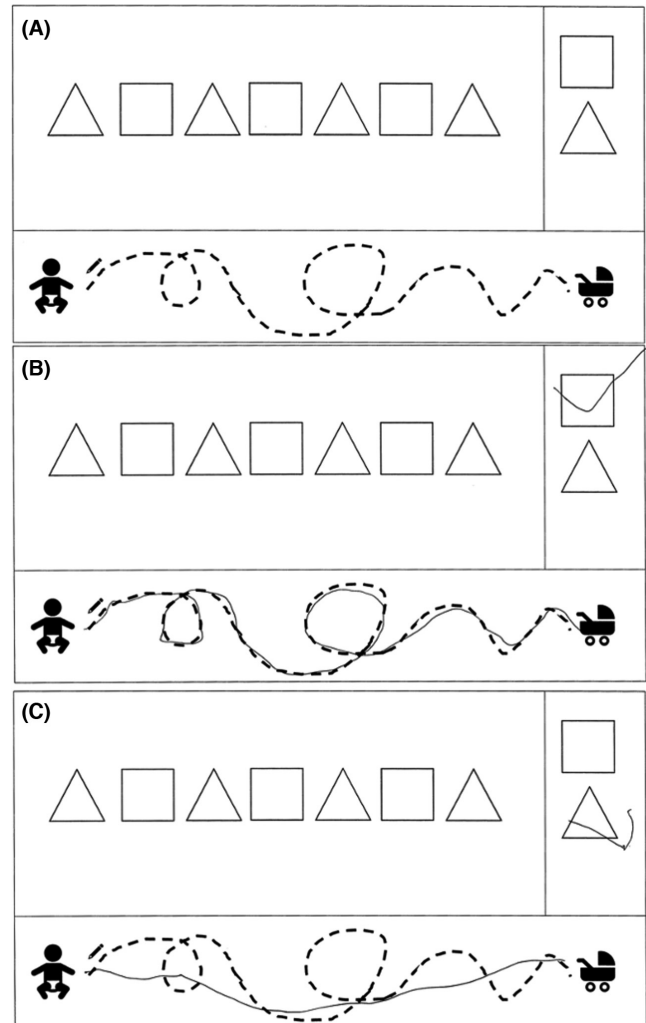
than their peers. Similarly, following TDIs, children have reported that the subsequent consequences negatively impact their oral-health-related quality of life.<sup>5</sup> Consequently, these children experience diminished self-esteem due to their appearance, especially when left untreated, and they were often judged poorly by society.<sup>6</sup> Nevertheless, besides the reports mentioned above, there is limited qualitative data on the psychosocial impacts of TDIs in preschool children.<sup>5</sup>

Children's social participation in early learning centres and/or primary schools depend on their peers' social acceptance. Most often, their personal contact experiences, perception of parental behaviour and self-efficacy beliefs predict children's attitudes towards their peers.<sup>7</sup> Rodd et al.<sup>8</sup> in 2010 stated that children aged 11 to 12 years viewed photographs of children with visible incisor trauma more negatively than the same child with normal incisor appearance, whereas children aged between 14 and 15 years did not. However, attempts to understand young children's lives and experiences are often challenging due to age, size and verbal skill asymmetries between investigators and their respondents. To date, there is limited understanding of children's attention and/or perception of TDI outcomes. In addition, it is unclear what preschool children see in their peers. For example, do they notice fractured or discoloured teeth? When does this capacity emerge in their development, and are there any associated limitations?

Recently, innovative approaches such as eye-tracking technology have been increasingly used to overcome potential social and communication barriers in health research.<sup>9,10</sup> These creative task-based activities are simple and effective, they engage young children to participate actively, are more fun than traditional methods, and importantly provide an objective understanding of children's perception. Infants and young children are often exposed to pictures early in life. Previous studies have established that children can use photos referentially to represent objects in the real world.<sup>11</sup> Furthermore, quantitative measures, such as eye movement analysis using hidden Markov models (EMHMM <http://visal.cs.cityu.edu.hk/research/emhmm/>), will facilitate the understanding of children's eye movements in both spatial and temporal dimensions.<sup>12</sup> Therefore, the aim of this child-centred visual task-based study was to explore individual differences among preschool children's eye movement patterns and their visual attention to typical outcomes of TDIs to the primary teeth. The assumption was that children would fixate on locations of high interest.

## 2 | MATERIAL AND METHODS

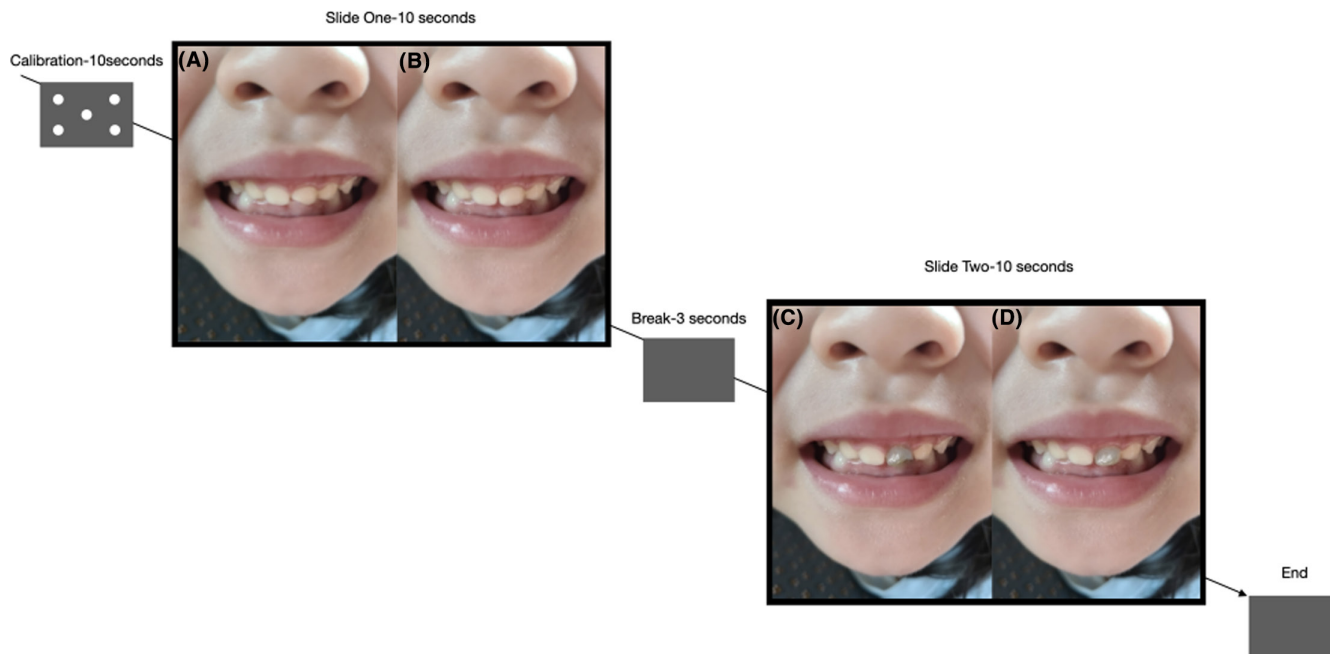
The Human Research Ethics Committee at the University of Western Australia (Reference: RA/4/1/9331) approved this study. Thirty-three childcare centres within a 25 km radius around the central business district in metropolitan Perth were invited, and 12 childcare centres agreed to participate in the study. Participants and their parents received information outlining the project details. Parents and/or legal guardians provided informed consent before study commencement.



**FIGURE 1** (A) Before viewing the pictures, all children were presented with two activities: Complete the pattern and join the dots in a line (B) all exercises complete or (C) incomplete

A total of 155 healthy preschool children aged between 2.5 and 5.5 years participated in this study. Children with associated medical conditions and/or syndromes, atypical development and reported vision or hearing issues were excluded. Before viewing the pictures, all children undertook two activities: (i) complete the pattern and (ii) join the dots in a line (Figure 1) which they could complete in their own time. These activities facilitated grouping of the children based on their ability to follow instructions and their manual dexterity. In addition, this strategy enabled the data to be analysed based on gender (male, female), age (2.6–3.5 years, 3.6–4.5 years, and 4.6–5.5 years) and the activity (complete or incomplete).

Tobii Studio software (Tobii) was installed onto a laptop computer (Hewlett Packard) connected with a Tobii Pro Nano screen-based eye-tracking camera recording at 60 frames per second. This laptop was set up in the childcare centres so the participants could independently view the images in a quiet room seated on a stable chair approximately 30 to 50 cm away from the laptop. All participants viewed the same pictures randomly displayed on a computer screen (Figure 2). A frontal photograph of a 3-year-old exhibiting a



**FIGURE 2** Eye-tracking sequence starting with calibration, then slide one, presenting images (A) showing crown fracture of tooth 61 and (B) a healthy primary dentition. A break followed this, and children viewed slide two, which consisted of images (C) crown fracture of tooth 61 with discoloration, and (D) discoloured tooth 61

| Gender (n)  | Activity   | Age (years) |         |         | Total |
|-------------|------------|-------------|---------|---------|-------|
|             |            | 2.6–3.5     | 3.6–4.5 | 4.6–5.5 |       |
| Male (83)   | Incomplete | 21          | 9       | 0       | 30    |
|             | Complete   | 9           | 21      | 23      | 53    |
| Female (72) | Incomplete | 16          | 3       | 0       | 19    |
|             | Complete   | 8           | 19      | 26      | 53    |
| Total       |            | 54          | 52      | 49      | 155   |

**TABLE 1** Study participants details based on gender, age and activity completion

complete smile with a healthy dentition was obtained using a digital camera (exposure time: 1/200s, aperture: f/8.0, sensitivity: ISO 200, Canon EOS 200D, Canon Inc.) with a macro lens (Canon EF 100mm f/2.8 Macro USM, Canon Inc.) and flashlight (Canon Speedlite 580EX II, Canon Inc.) under standardized conditions. The initial resolution of the images was 4752x3168 pixels. Subsequently, the eyes, neck, clothes and other peripheral features were cropped. Finally, a crown fracture and discoloration were superimposed and photoshopped [Photopea (<https://www.photopea.com/>)] as shown in Figure 2.

The first slide consisted of (i) a crown fracture of tooth 61 and (ii) healthy primary maxillary incisors. Subsequently, the children viewed another slide consisting of two images with (iii) the 61 discoloured and (iv) a crown fracture with discoloration of the 61.

All participants were positioned in the middle of the camera's field of view, and the screen and camera were adjusted to capture the participants' eyes movements. The investigation started with a two-point eye-tracker calibration exercise, using an animation video of a duck that made an alerting sound to gain attention and moved across the screen, taking approximately 10s. All participants

were calibrated to the eye-tracker to ensure standardization. Subsequently, each participant viewed the same images (Figure 2) with a break in between. Images were randomly sequenced and the child did not perform other tasks until the screen went blank, indicating the end. In addition, the instructions were very minimal to avoid differing interpretations of the task at hand. Subsequently, each participant's fixation points and pupil diameter (at each 300ms) were exported into an Excel spreadsheet (Microsoft Corp.).

The eye-fixation data were analysed using EMHMM, which incorporated individual differences in spatial (eye-fixation locations) and temporal dimensions (the order of eye-fixation sites). In order to assess participants' eye movement patterns, equal-sized fixed regions of interest (ROI) were predetermined as ROI 1 and ROI 2 around the dentition. The assumption was that each ROI would follow a 2D Gaussian distribution. A two-tailed *t*-test was used to compare the means for normally distributed and skewed data with the *p* values set at .05 for statistical significance. In addition, a *t*-test was computed to compare eye movement patterns and consistency measures between gender and activity groups, while ANOVA was used

for age groups. The transitions among the ROIs were summarized into a transition matrix showing the probability of eye gaze moving from a previously viewed ROI to the current ROI. Subsequently, individual HMMs were clustered into groups according to their similarities and the ROI transition sequences identified representative eye movement patterns among the participants. Finally, the raw data were analysed using EMHMM and GraphPad Instat.

### 3 | RESULTS

A total of 155 children participated and their demographics are summarized in Table 1. As young as 2 years, all preschool children exhibited fixations on all images. In addition, they demonstrated two different eye movement patterns (Figures 3 and 4), namely distributed and selective, whose difference reached significance (independent *t*-test,  $p < .05$ ).

For slide 1 (fractured 61 vs healthy dentition), children who exhibited a distributed eye movement pattern ( $n = 136$ ) showed an equal chance of starting on either ROI (priors = 0.50) - see Figure 3. They remained in the same ROI afterwards (ROI 1 = 55%, ROI 2 = 59%) or switched to the alternate ROI (ROI 1 = 41%, ROI 2 = 45%). Thus, children following a distributive pattern had an equal chance of noticing either image and often shifting between them. However, for children exhibiting a selective pattern, 42% started fixating on ROI 1, of whom 91% remained in the same ROI. The remaining children (58%) started fixations on ROI 2, of whom 86% remained in the same ROI. Thus, most children exhibiting selective pattern remained in the same ROI they first focused on.

Overall, all children preferred ROI 2 (healthy dentition) compared with a hypothetical mean of 50% [one sample *t*-test preferential mean for ROI 1 = 0.46, SD = 0.18,  $t(154) = 2.97$ ,  $p < .01$ ]. Females exhibited higher fixations on ROI 2 [one sample *t*-test preferential mean for ROI 1 = 0.45, SD = 0.16,  $t(154) = 2.59$ ,  $p < .01$ ]. The children who did not complete the activity exhibited a distributed pattern, switching between ROI 1 and ROI 2, whereas those who completed the task spent more time focusing on ROI 1. Children following a selective pattern preferred to look at ROI 2, ie. the healthy dentition [preferential mean for ROI 1 = 0.43, SD = 0.18,  $t(82.95) = 2.21$ ,  $p = .03$ ] while those following the distributed pattern did not have any preference. No significant differences [ $t(81.48) = 0.13$ , 95% CI = -0.21-0.18,  $p = .89$ ] were evident in the mean pupil diameter between ROI 1 (3.46 mm) and ROI 2 (3.47 mm, MD ± SEM = -0.01 ± 0.10) (Table 2).

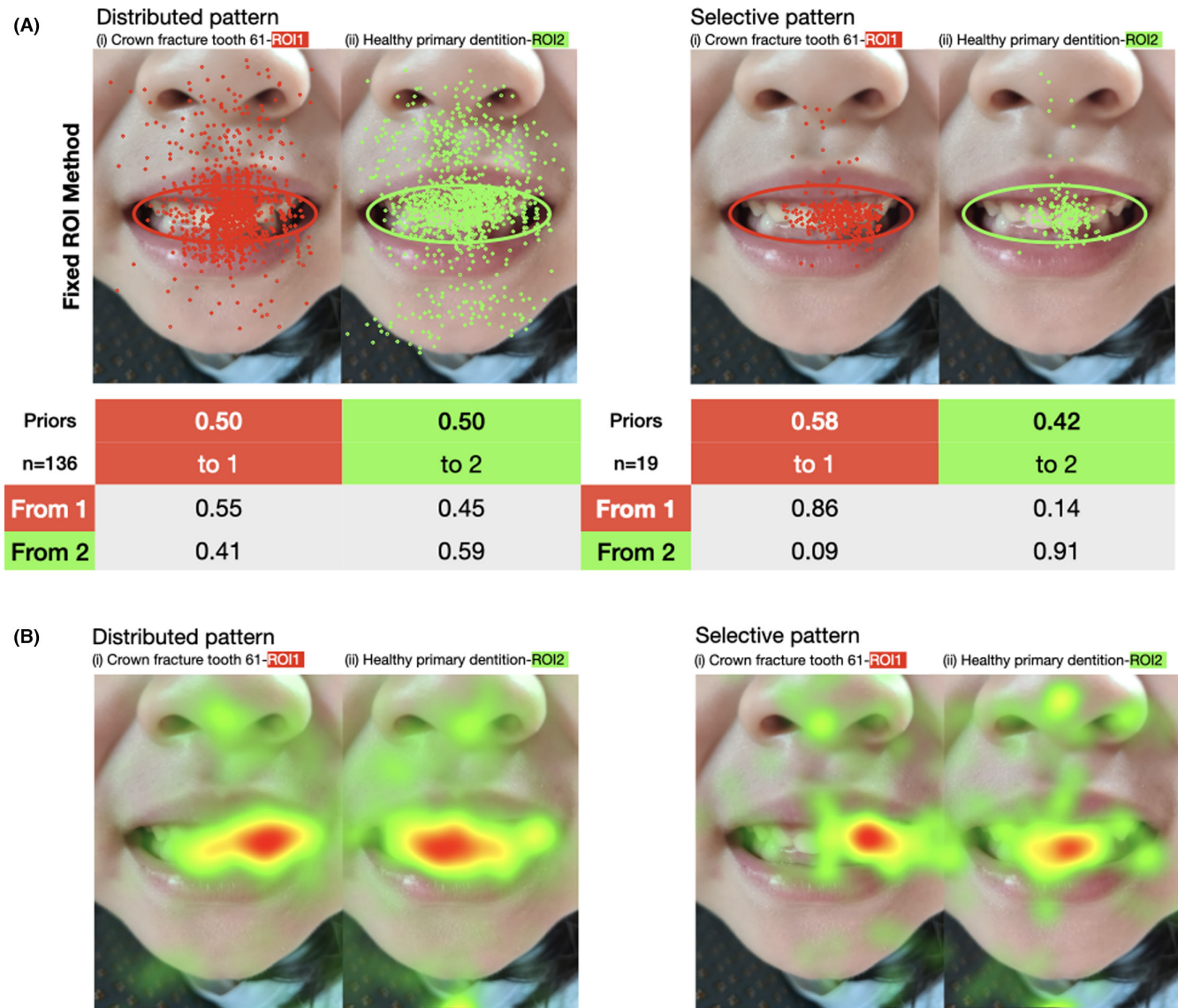
Children when viewing slide 2 (discoloured 61 vs. fractured and discoloured 61) exhibited similar probability of starting their fixations on either ROI (Figure 4). In the distributed pattern ( $n = 122$ ), 57% of the children remained in the same ROI they first focused on, while 43% shifted to the other ROI. Conversely, in the selective pattern ( $n = 33$ ), almost all children stayed in the same ROI they first focused on, i.e. ROI 1 = 90%, and ROI 2 = 92%. No significant differences were evident in preference for ROI 1 between

children using selective or distributed patterns [mean of distributed pattern = 0.53, selective pattern = 0.4;  $t(27.60) = 0.45$ ,  $p = .62$ ]. Similarly, the mean pupil diameter between ROI 1 (3.20 mm) and ROI 2 (3.14 mm, MD ± SEM = 0.06 ± 0.07) was not significantly different [ $t(135.5) = 0.21$ , 95% CI = -0.07-0.19,  $p = .95$ ] (Table 2).

### 4 | DISCUSSION

To the best of the authors' knowledge, this study is the first to investigate preschool children's eye movement patterns to typical consequences following TDIs to primary teeth. For most children, images with typical outcomes of TDIs did not hold or capture their visual attention. They switched their fixations between the presented images, indicating no preference between teeth affected or unaffected by TDIs. However, a minority preferred a healthy dentition image over that of a fractured incisor tooth. A possible explanation for children's lack of attentional bias between the images may be their young age or understanding of TDIs. In addition, children generally use the mouth region as an essential source of social information through development, especially during language acquisition which is likely a reason they noticed teeth in the presented images.<sup>13-15</sup>

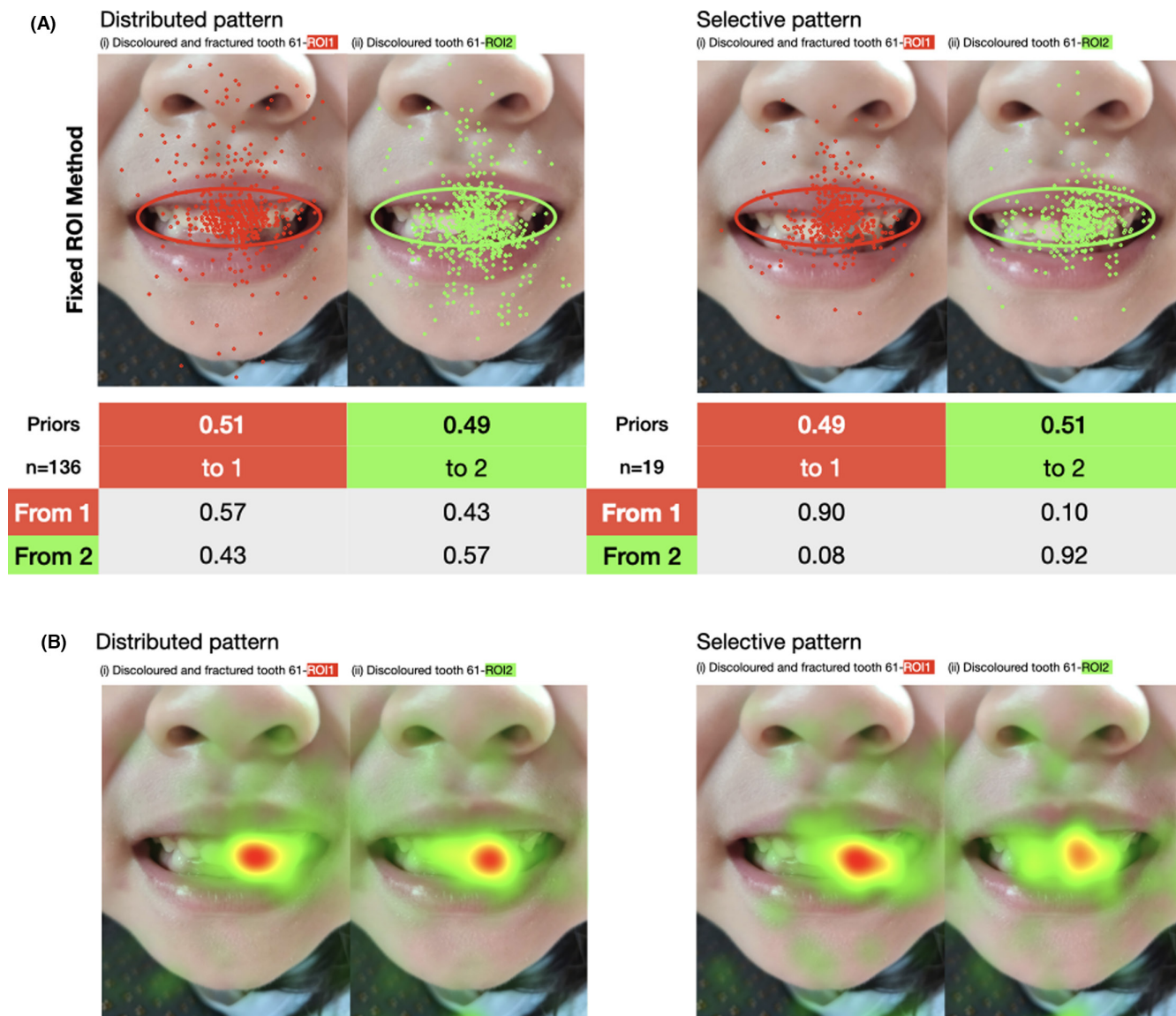
All children were healthy with no reported cognitive, visual, hearing or developmental issues. The study was conducted in a spacious, well ventilated, optimally illuminated quiet room during regular working hours of the day-care centres. A 14-inch LCD screen with 1366x768 resolution, 32-bit colour, the maximum luminance of 250-300 cd/m<sup>2</sup>, contrast ratio of 1000:1, a sampling rate of 60 hz and an aspect ratio of 16:10 was used. The included images were of typical outcomes following TDIs in the primary teeth. In addition, the children's pupil responses were assessed to eye-tracking stimuli as pupil dilation in constant lighting suggests a change in the level of surprise.<sup>16</sup> There were no significant changes in pupil diameter, implying that the TDI outcomes did not stimulate or surprise the children, which is understandable given the mild nature of the presented stimuli. This could also indicate that the children perceived their peers' fractured teeth and tooth discolourations differently from their parents.<sup>3</sup> However, given their young age and limited attention span, this study did not include additional images to cover the entire range of TDI consequences. As illustrated in Figure 2, the clinical images were presented concurrently to fit the EMHMM model. A sequential display of individual images would better suit pupillometry analysis as one cannot appropriately isolate the two concurrently presented images. Hence, the results may vary if the children viewed the TDI images sequentially instead of accompanying pictures, which requires further investigation. Therefore, a cautious interpretation of the pupillometry findings is essential while extrapolating these findings. Nevertheless, clinicians should be aware that treating the primary teeth following a TDI for aesthetic reasons is primarily to appease the parents' perception that their child will be visually acceptable to their friends and perhaps to other adults.



**FIGURE 3** (A) Two eye movement patterns (distributed and selective) exhibited by 155 preschool children, and the fixed regions of interest (ROI) analysis for images with and without crown fracture. The ROIs are defined as elliptical areas in the mouth region and represented as ROI 1: Showing crown fracture on tooth 61 and ROI 2: Healthy primary dentition. Note: Small circles show raw fixation locations, and the colour of the small circles indicate ROI assignments. Priors indicate the probability that a fixation sequence starts from the corresponding ROI. The transition matrix suggests the likelihood of eye gaze transits between the ROIs. For example, in the distributed pattern group, children showed a 50% chance of their first fixation in ROI 1 or ROI 2. After that, they remained in the same ROI (ROI 1 = 55%, ROI 2 = 59%) or switched ROI (ROI 1 to ROI 2 = 45% and ROI 2 to ROI 1 = 41%). (B) Shows the representative heatmaps for each eye movement pattern. Note the area in red indicates the maximum focus, which is predominantly on teeth for both groups

Although eye-tracking and EMHMM measures are better than a traditional interview and questionnaire approach for apprehending children's perceptions, some interpretive challenges exist. For example, children did not answer specific questions regarding their choice or preference due to their young age, verbal skill asymmetries and to avoid potential information bias. Hence, fixation data alone may not accurately represent choice or judgment. EMHMM considers the sequence of viewed ROIs to develop a Markov process using the children's previously viewed ROI to inform their subsequently considered ROI.<sup>17</sup> Each child's HMM is estimated from their eye movement

data using a variational Bayesian approach to determine the optimal number of ROIs automatically.<sup>18</sup> Consequently, this data-driven approach generates the children's most representative eye movement patterns. Therefore, the difference in the gaze transition behaviour between the two images is only noticeable via EMHMM and is not evident when looking at heatmaps of eye fixations (Figures 3 and 4). Furthermore, by clustering individual HMMs, common patterns among preschool children were identified with specific ROIs and transitions among the ROIs, which strengthens the present study findings. Hence, EMHMM is a valuable tool for determining children's



**FIGURE 4** (A) Two eye movement patterns (distributed and selective) exhibited by the 155 children, and the fixed regions of interest (ROI) for images with discoloured tooth 61 and discoloured and fractured tooth 61. The ROIs are defined as elliptical areas in the mouth region and represented as ROI 1: Discoloured tooth 61, and ROI 2: Discoloured and fractured tooth 61. Note: Small circles show raw fixation locations, and the colour of the small circles indicate ROI assignments. Priors indicate the probability that a fixation sequence starts from the corresponding ROI. The transition matrix suggests the likelihood of eye gaze transits between the ROIs. For example, in the distributed pattern group, children showed 51% of their first fixation ROI 1 and 49% in ROI 2. They remained in the same ROI (ROI 1 = 57%, ROI 2 = 57%) or switching ROI (ROI 1 to ROI 2 = 43% and ROI 2 to ROI 1 = 43%). (B) Representative heatmaps for each eye movement pattern. Note the area in red indicates the maximum focus, which is predominantly on teeth affected by discoloration for both groups

**TABLE 2** Pupillometry analysis for the 155 preschool children showing their mean pupil diameter while viewing images of primary teeth, which exhibited typical outcomes following traumatic dental injuries

| Images  | ROI 1 | ROI 2 | MD ± SEM     | 95% CI        | t    | df     | p   |
|---------|-------|-------|--------------|---------------|------|--------|-----|
| Slide 1 | 3.46  | 3.47  | -0.01 ± 0.09 | -0.21 to 0.18 | 0.13 | 81.48  | .89 |
| Slide 2 | 3.21  | 3.15  | 0.06 ± 0.07  | -0.06 to 0.19 | 0.95 | 135.50 | .95 |

Note: slide 1-ROI 1: Fractured tooth 61, ROI 2: No fracture; slide 2-ROI 1: Discoloured tooth 61, ROI 2: Discoloured and fractured tooth 61.

eye movement patterns and preferential ROIs with a high spatial and temporal accuracy. Nevertheless, future studies could explore using pictures of other possible consequences in both the primary and

permanent dentitions, including children from different age groups, to fully understand the developmental origins of differences in visual attention to expected outcomes following TDIs in children.

## 5 | CONCLUSION

This study illustrated that preschool children notice teeth. However, most of them did not have an attentional bias, implying that they did not interpret these TDI outcomes negatively. Only a few children avoided looking at images with TDIs indicating a potential negative impact. The EMHMM approach is appropriate for assessing inter-individual differences in children's visual attention to TDI outcomes.

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### CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

### AUTHOR CONTRIBUTIONS

Vanessa Cho contributed to conception, design, data acquisition, and interpretation, performed the statistical analysis, drafted the manuscript. Janet Hsiao contributed to data acquisition and interpretation, performed the statistical analysis and critically revised the manuscript. Nigel King and Hien Ngo contributed to conception and design and critically revised the manuscript. Antoni Chan contributed data acquisition and interpretation, performed the statistical analysis and critically revised the manuscript. Robert Anthonappa contributed to conception, design, data acquisition and interpretation and critically revised the manuscript. All authors gave their final approval and agree to be accountable for all aspects of the work. Open access publishing facilitated by The University of Western Australia, as part of the Wiley - The University of Western Australia agreement via the Council of Australian University Librarians.

### DATA AVAILABILITY STATEMENT

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

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