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Visual search behaviour in young cyclists: A naturalistic experiment

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1. Introduction

Cycling, as a moderate intensity exercise, is a suitable strategy for children to increase their physical activity levels (Panter, Jones, Van Sluijs, & Griffin, 2010) to improve health and fitness (de Hartog, Boogaard, Nijland, & Hoek, 2010; Stewart, Vernez Moudon, & Claybrooke, 2012) whilst reducing cardiovascular risk factors (Oja et al., 2011). Although cycling for leisure, or as mode of transport, introduces new health risks associated with accidents, injuries and exposure to air pollution, the benefits of cycling still outweigh these risks (de Hartog et al., 2010; Hillman, 1993). Particularly as adopting active travel behaviour at an early age increases the probability of adopting this behaviour in adulthood (Telama, Yang, Viikari, Välimäki, Wanne, & Raitakari, 2005). However, the uptake of cycling as a mode of transport in children is low, with large variance between countries. In contrast to the Netherlands, where ~50% of children cycle to school, in the UK only 3% of pupils aged 5–16 cycle to school (Department for Transport. (2018) (2018), 2018). Determinants of the low uptake of cycling as a mode of travel in youth are wide ranging, incorporating individual, environmental and external factors with a key role for parents in the decision making process (Panter, Jones, & Van Sluijs, 2008). The environmental factors, reflected in road traffic density and provision of cycling facilities, influences the parental and children's perceptions of personal safety in the environment. Within younger children, it is the parental risk perception associated with the dangers of cycling that influences the opportunity of youth to take up cycling as a mode of transport (Panter et al., 2008; Pucher & Dijkstra, 2000). Concurrently to examining the objective dangers, reflected in road design and traffic density, it is equally important to consider the abilities of children to identify and anticipate dangerous situations as well as adapting their behaviour according to the situation. This process, commonly referred to as hazard perception, can be defined as the ability to anticipate dangerous situations on the basis of perceptual evidence (Groeger & Chapman, 1996). Hazard perception depends on cognitive abilities, which develop in children as a function of age. Research suggests that from the age of six, children enhance their hazard perception from solely identifying salient information (e.g., cars) to "reading" more complex travel scenes to evaluate potential dangerous scenes of less salient nature (e.g., considering not having a line of sight and covert hazards, Meyer, Sagberg, & Torquato, 2014). These hazard perception abilities are typically examined in video-based hazard perception paradigms where reaction times and response rates from the perspective of a road user is investigated. Within a cycling simulator, Igari, Shimizu, and Fukuda (2008) identified that young adult cyclists looked more at task irrelevant objects in the environment compared to elderly cyclists, which was likely due to a lower mental load required to complete the task, subsequently resulting in more 'spare time' to look at task irrelevant areas. Zeuwts, Vansteenkiste, Deconinck, Cardon, and Lenoir (2017) identified that young cyclists were slower and less likely to identify covert hazards in comparison to adult cyclists, whilst these differences where not apparent in overt hazards. Whereas, Hodgson and Worth (2015) identified the children who completed cycle training (e.g., bikeability in the UK) with on-road training elements and safety training performed better in an online hazard perception task.

There are several limitations with using video-based approaches to measure hazard perception in cyclists. The direction of overt visual attention (i.e., visual search behaviour) will affect the ability to identify potential hazards and adopt suitable avoidance strategies, however, this not commonly assessed. More importantly, visual search behaviour in video-based stim-

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ulation is adapted due to a reduction in contextual information to examine (Dicks, Button, & Davids, 2010) whilst adapting behaviour of participants (e.g., avoidance behaviour) is often not possible. Hence, assessing visual search behaviour in naturalistic environments allows for the examination of real life behaviour and hazard identification with a reduced level of control over the study (e.g., it is not possible to create dangerous situations).

However, there is relatively little information investigating the influence of the environment on visual search behaviour of cyclists. Vansteenkiste, Cardon, D'Hondt, Philippaerts, and Lenoir (2013) identified that adult cyclists reduced their speed and redirected their visual attention from looking straight ahead, to the near pathway, when task complexity increased (i.e. cycling on wide vs narrow paths). In a separate study, when cycling in a naturalistic environment, adult cyclists adapted their visual behaviour from looking at more distant aspects in the environment (i.e. straight ahead), when on a recently resurfaced, high quality road surface, to look at areas on the road in close proximity, with a poor road surface, characterised by broken and unstable slabs (Vansteenkiste, Zeuwts, Cardon, Philippaerts, & Lenoir, 2014). In a study with young children, Vansteenkiste et al. (2017) demonstrated that when cycling on a 700 m low quality segregated cycle path, compared to high quality segregated cycle path that children, and experienced adults, increased the time spent looking at the path and reduced their horizontal gaze distribution (i.e. the amount they looked around in the environment). Of note, difference between groups were found (irrespective of terrain quality) whereby children spent less time looking at the path and more time at the sides and immediate surroundings compared to adults. This is presumably a strategy to identify potential hazards or alternatively reflects the lower speed of young cyclists where bike stability and positioning on the cycle path were maintained by directing visual attention to the sides of the path. Although completed in a naturalistic environment, the segregated cycle path and environment used by Vansteenkiste et al. (2017) had a representative design; the cycle path was separated from other road users (e.g., pedestrian and cars) by bushes/grass and other cyclists were requested not to pass the participants whilst data was being collected from the participants cycling on the path. Hence, the one piece of research investigating the impact the environment has on the visual search behaviour of children when cycling (Vansteenkiste et al., 2017) was completed in a relative controlled environment with limited distractors/hazards.

1.1. Aim

The aim of the current study was to extend the findings presented by Vansteenkiste et al. (2017) by examining visual search behaviour to task-relevant and irrelevant features of children cycling through naturalistic environments of different task complexity. Based upon the work by Dozza and Werneke (2014), on the occurrence of critical events in adult cyclists, we compared cycling in low quality terrain, occluded line of sight and in a high distraction environment. We hypothesise that visual search behaviour would be directed more towards the path in poor terrain compared to other scenarios and that a high distracting environment will attract the attention of young cyclists at the expense of looking in the direction of travel. Additionally, based on the work of Vansteenkiste et al. (2017) of the comparison of cycling on poor quality and high quality road surfaces, we hypothesise that visual search behaviour becomes less predictable in more distracting environment.

2. Method

2.1. Participants

Fourteen children (11 male, 3 female) aged 7.8 ± 1.3 years (mean ± SD) with a range of cycling experience were recruited through opportunistic sampling to the study. None of the children had received centrally organised cycling awareness training (e.g., bikeability) at their respective school. The tenants of the Declaration of Helsinki were observed and Anglia Ruskin University's Ethical Committee approved the study. Prior to participation, written informed consent was obtained from both the participant and the participant's parent. Each parent completed a questionnaire relating to their child's cycling experience (Table A1).

2.2. Protocol

Participants were asked to cycle in a naturalistic environment, on their own bike, along a path (2.3 m wide) around a recreation ground, completing two consecutive loops (Fig. B1). The total route distance was 1.08 miles (1.74 km). The width of the path was comparable to the recommended cycle lane width of 2.5 m (Sustrans, 2014). All participants recruited to the study remembered playing at the adventure playground (within the recreation ground) on at least one occasion; they had some familiarity with the environment. Testing took place in daylight hours, on either a weekend or early evening to ensure the recreation ground was busy.

Within the recreation ground, the path is permitted for use by both cyclists and pedestrians. Key facilities within the recreation ground include a toilet block, paddling pool, adventure playground with basketball court, two tennis courts (at opposite ends of the recreation ground) and two soccer pitches. Benches, bins and mature trees lined the path throughout the recreation ground (Fig. B1).

Prior to cycling around the recreation ground, each participant was informed that this was not a race, or a test of their cycling ability. They were asked to cycle as they would normally do when cycling to school or for recreational purposes.

Participants were also instructed that if they encountered an obstruction in the path (e.g. pedestrian or cyclist), if they thought it was safe, they were to cycle around them, otherwise they were to slow down and wait until it was safe to continue.

Throughout the entire trial, the participant's parent was required to cycle behind them. Parents were given the prior instruction to provide typical verbal cues to direct their child as they would when cycling. Both participant and parent were required to wear a cycle helmet to participate.

2.3. Equipment

Visual search behaviour (of the child only) was recorded using an SMI iViewETG head mounted mobile eye tracker (SensoMotoric Instruments Inc, Warthestr; Germany, Ver. 1.0). Details regarding the eye tracker have been reported previously (Timmis et al., 2017). Data from the eye tracker were recorded on a mini laptop (Lenovo X220, ThinkPad, USA) with iView ETG (Ver. 2.0) recording software installed. A three point eye calibration was performed to verify point of gaze and the calibration was checked following completion of cycling around the recreation ground. The laptop was placed in a backpack which was worn by the participant during testing. Participants recruited had experience of cycling wearing a backpack (e.g. cycling to school or to their sports club) so that they would not be unfamiliar with the mass (from the laptop) in a backpack when cycling.

2.4. Scenario characteristics

Three scenarios from the first lap cycling around the recreation ground were retained for further analysis;

Scenario 1. High Distraction

Cycling past the adventure playground (see Fig. 1) containing a paddling pool, basketball court, multiple slides and swings. The playground was surrounded by metal railings of 1 m in height. Along this section of path, there were 2 gates into the adventure playground and 5 small pot holes were encountered. This part of the recreation ground always contained multiple pedestrians, dog walkers and cyclists along the path. Children were playing in the park, bikes parked against the metal railing and people walking into and existing the park. Eye tracking data was tracked from 10 m before starting to pass the playground up until the instant whereby the adventure playground was past.

The total length of this scenario was 79 m.

Scenario 2. Intersection

Cycling up to a fork in the path and around a bend, which was occluded with dense foliage (Fig. 2). Participants cycled through dense foliage (trees and bushes) on either side of the path, around a left hand (∼90°) bend and past a tennis court. Six small pot holes were encountered in this section. Total length of this scenario was 67 m. Visual search data was tracked from the instant the *Intersection* was clearly identifiable from the scene camera up until the participant had cycled around the bend and was cycling along a straight section of the path. Landmarks (i.e., tree and start of tennis court) from the scene camera were used to identify start and end of the scenario (Fig. B1).

Fig. 1. Start of *High Distraction* scenario. Of note, the basketball court, slides and swings are located in the distance, behind the large green trees. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 2. Start of ***Intersection*** scenario. When approaching the Fork in Path, participants were required to take the left path.

Scenario 3. Poor Terrain

Cycling up to and around a sharp bend containing irregular terrain. Participants cycled along a section of path, which was in poor condition containing 7 large pot holes and gravel. Immediately before a 90° left hand bend, there was a drop in the level of the path into a large area in the path, which had been filled with lose gravel (see Fig. 3). Total length of this scenario was 31 m.

Landmarks (i.e., surface change and trees) from the scene camera were used to identify start and end of the scenario (Fig. B1).

2.5. Data analysis

Visual search data from the eye tracker was analysed offline using BeGaze software (Ver.3.4) and was subject to frame-by-frame analysis. Areas of interest (AOI) were defined as key locations within the visual scene based upon the work by Vansteenkiste et al. (2014, See Table 1). To record the number of times participants looked from one place in the environment to another (i.e. number of dwells during the trial), a coding window was created. This ensured that after each saccade, a new dwell was coded, either to a new AOI or, the reorientation of gaze within the same AOI. From this, dwell time (the total length of time the participant gazed at a specific AOI) and number of dwells (number of different dwells onto an AOI) were derived.

The following variables were used to analyse eye tracking data;

Fig. 3. Section of *Poor Terrain* Scenario, highlighting the drop in the level of the path into an area which had been filled with lose gravel, immediately before a 90° left hand bend.

1. Scenario length (seconds, sec).
2. Number of dwell locations – total number of different AOIs (see Table 1) looked at within the scenario.
3. Relative number of dwells on each AOI - higher number of dwells to a particular AOI provides an indication of the AOI's relative relevance to information processing and subsequent task execution (Mann, Ho, De Souza, Watson, & Taylor, 2007). Calculated as a percentage overall scenario length to account for any differences in actual scenario length between scenarios.
4. Relative dwell time on each AOI - longer time spent dwelling at a particular AOI allows more information to be obtained, indicating greater relevance to information processing and subsequent task execution (Mann et al., 2007). Calculated as a percentage overall scenario length to account for any differences in actual scenario length between scenarios.

2.6. Entropy analysis

Gaze transitions from one AOI to a different AOI within the environment were examined though an entropy analysis. Entropy provides a global measure of visual search behaviour (Schieber & Gilland, 2008), through measuring the randomness (or orderliness) of the visual search behaviour (Tole, 1983); a higher entropy indicates greater randomness in the transition behaviour. These changes in entropy reflect differences in the acquisition of visual information as a function of visual-spatial task load (e.g., Schieber & Gilland, 2008). It is possible that when cycling, the infrastructure design and amount of visual relevant and irrelevant information will influence the visual-spatial task load placed on the cyclist, affecting the acquisition of visual information. Therefore, an increase in entropy would be reminiscent of a more varied acquisition of visual information, whereas a reduced entropy would reflect a more focussed acquisition of visual information. The entropy analysis considered the transitional probabilities associated with gazes across the AOIs highlighted in Table 1, and follows the approach utilised by Allsop and Gray (2014). Gaze position at AOI was used to construct first order Markov matrices. Three matrices for each of the three scenarios (*High distraction, Intersection, and Poor Terrain*) were constructed for each participant. The first order transition matrices allowed the calculation of the total number of dwells for each participant when undertaking each condition. First order transition matrices were converted into conditional transition-probability matrices. The entropy of each conditional transition-probability matrix was calculated as described in Allsop and Gray (2014).

2.7. Statistical analysis

All participants successfully cycled around the recreational park twice without accident. Eye tracking data from all participants achieved a tracking ratio above 90%; deemed an acceptable threshold to ensure that only reliable eye-tracking data is included (Vansteenkiste et al., 2014).

Intra-rater and inter-rater reliability of the frame-by-frame analysis of a random selection of 10% was conducted. An intra-rater reliability agreement (HL rated twice) of 99% was identified for the total number of dwells within the trial ($r = 0.99$), the relative number dwells at *Non-Path users* ($r = 0.99$), the relative dwell time at *Non-Path users* ($r = 0.99$) and *Pot hole* ($r = 0.98$). An inter-rater reliability agreement (HL, KvP and MT mapped the same trials) of 96% was identified for the total number of dwells within the trial ($r = 0.94$), the relative number dwells at *Non-Path users* ($r = 0.95$), the relative dwell time at *Non-Path users* ($r = 0.91$) and *Pot hole* ($r = 0.89$).

Statistical analysis was undertaken using a one-way repeated measures ANOVA with scenario (*High distraction, Intersection* and *Poor Terrain*) as the independent variable. Level of significance was accepted at $p < 0.05$. Post-hoc analysis (where appropriate) was completed using pairwise comparisons (Bonferroni correction). Effect sizes were calculated using Partial Eta squared η_p^2.

3. Results

3.1. Descriptive overview

Each participant passed an average of 7 ± 4 bikes parked on or next to the path in the *High Distraction* (study total of 102 bikes), 1 ± 1 in the *Intersection* (study total of 11 bikes). There were no parked bikes encountered by any participant in the *Poor Terrain*. Each participant encountered an average of 2 ± 1 Path users in the *High Distraction* (study total of 22 Path users), 1 ± 1 in the *Intersection* (study total of 8 Path users) and <1 ± <1 in the *Poor Terrain* (study total of 2 Path users). A general overview of visual search behaviour across conditions is presented in Fig. 4. Across the three conditions, children predominantly look at the path and potholes on the path.

3.2. Global measures

Scenario length

The scenario had a significant main effect on overall time ($p < .001$, $\eta_p^2 = 0.93$). Participants took significantly longer to cycle through the *High Distraction* (20 ± 3 s) compared to both *Intersection* (18 ± 3 s) and *Poor Terrain* (8 ± 2 s). Time taken

Table 1
Definition of each area of interest (AOI) used to analyse visual search data in all three scenarios.

AOI	Definition
Pot hole	When gaze is on the path, directed towards an undesirable location which the cyclist should avoid; considered poor quality terrain and typically consisted of a pot hole.
Near path	When the cyclist's front wheel is in view and the eyes are visually anchored at the path, ahead of the individual (approximate up to 3.5 m from the front wheel), being 'carried along' as the individual cycles (termed constant gaze episodes c.f. Patla & Vickers, 2003).
Path	When gaze is on the path where the participant is cycling (and not considered AOI *Near path* or *Pot hole*).
Total Path	Comprises the total of *Pot hole, Near path* and *Path* AOIs.
Side	When gaze is looking down at the edge of the path to the boundary of the path and grass.
Distraction	Looking into the adventure playground (scenario 1) or tennis court (scenario 2 and 3) at either people or key features.
Static Hazards	When looking at stationary bikes parked against railings or benches (positioned on the path) and trees close to the path.
Focus of Expansion (FOE)	When looking ahead, into the distance.
Path users	When looking at a person, dog or cyclist that was walking/cycling on the path.
No fixation/Other	When the eye tracker lost the recording of the participant's gaze or was directed to non-specified features in the environment.

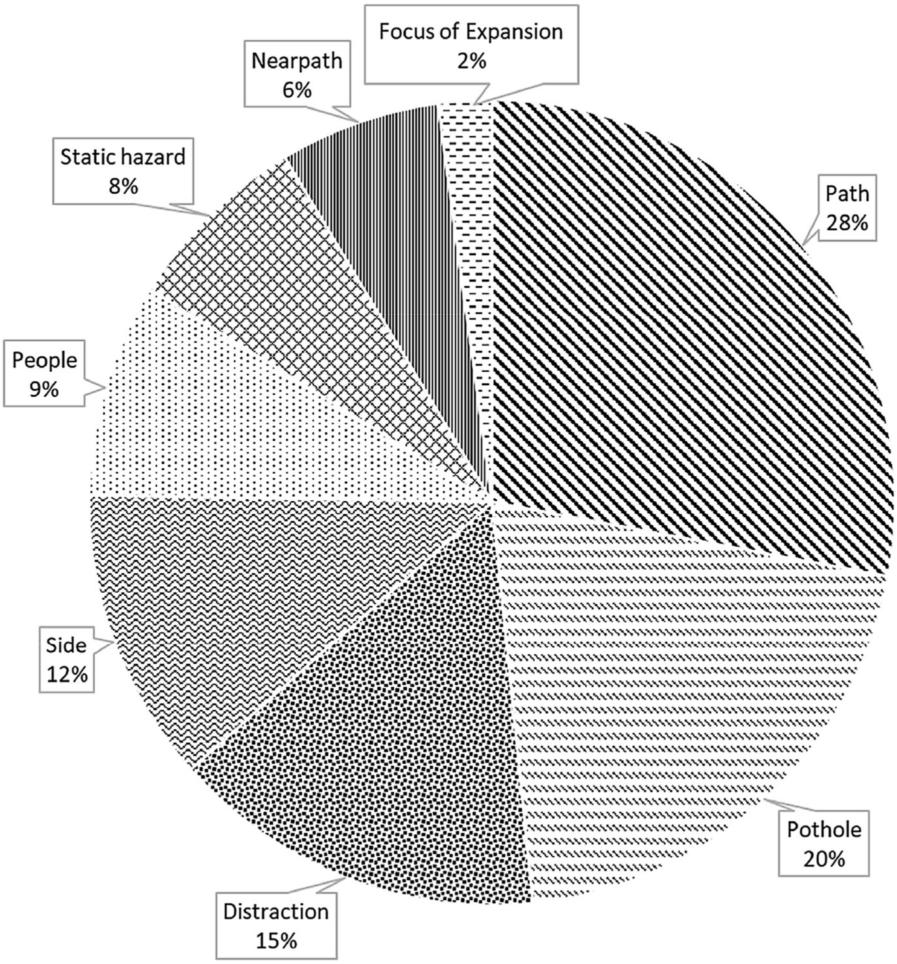

Fig. 4. Overview of the relative dwell time on the different AOIs collapsed accros the three conditions. The average relative dwell time to "No fixation/ Other" was 9%, and excluded from Fig. 4 for clarity.

to cycle through the *Intersection* was significantly longer than *Poor Terrain*. Due to these significant differences in time between scenarios, visual search behaviour is expressed as relative to trial time (see method).

Entropy

There was a statistically significant difference in both the entropy ($p < .001$, $\eta_p^2 = 0.36$) and the number of transitions ($p < .001$, $\eta_p^2 = 0.61$) of visual search behaviour between the scenarios. Post hoc analysis showed that entropy was lower in the *Poor Terrain* (0.79 ± 0.37 bits) compared to both *Intersection* (1.30 ± 0.27 bits) and *High Distraction* (1.32 ± 0.38 bits) scenarios. Additionally, post hoc analysis showed that number of transitions was lower in the *Poor Terrain* (15.64 ± 4.60) compared to both *Intersection* (45.64 ± 11.37) and *High Distraction* (48.50 ± 17.22) scenarios.

3.3. Relative number of dwells on each AOI

Total path

The scenario had a significant main effect on the relative number of dwells at *Total Path* ($p < .001$, $\eta_p^2 = 0.52$). Participants made significantly more dwells at *Total Path* in the *Poor Terrain* (58 ± 15%) compared to both *High Distraction* (33 ± 11%) and *Intersection* (47 ± 12%). There was also a significant increase in the relative number of dwells at *Total Path* in the *Intersection* compared to *High Distraction*.

Near path

There was no significant main effect of scenario on the relative number of dwells at *Near path* in *High Distraction* (7 ± 5%), *Intersection* (8 ± 7%) and *Poor Terrain* (5 ± 5%, $p > .05$, $\eta_p^2 = 0.13$).

Path

There was no significant main effect of scenario on the relative number of dwells at *Path* in *High Distraction* (25 ± 6%), *Intersection* (31 ± 7%) and *Poor Terrain* (24 ± 14%, $p > .05$, $\eta_p^2 = 0.13$).

Pot hole

The scenario had a significant main effect on the relative number of dwells at *Pot hole* ($p < .001$, $\eta_p^2 = 0.86$). Participants made significantly more dwells at *Pot hole* in the *Poor Terrain* (29 ± 11%) compared to both *High Distraction* (1 ± 1%) and *Intersection* (8 ± 4%). There was also a significant increase in number of dwells at *Pot hole* in the *Intersection* compared to *High Distraction*.

Side

The scenario had a significant main effect on the relative number of dwells at *Side* ($p < .001$, $\eta_p^2 = 0.51$). Participants made significantly more dwells at *Side* in the *Poor Terrain* (15 ± 9%) and *Intersection* (21 ± 7%) compared to *High Distraction* (7 ± 6%). There was no significant difference between *Poor Terrain* and *Intersection*.

FOE

There was no significant main effect of scenario on the relative number of dwells at *FOE* in *High Distraction* (4 ± 3%), *Intersection* 6 ± 6% and *Poor Terrain* (5 ± 10%, $p > .05$, $\eta_p^2 = 0.03$).

Distraction

The scenario had a significant main effect on the relative number of dwells at *Distraction* ($p = .001$, $\eta_p^2 = 0.40$). Participants made significantly more dwells at *Distraction* in the *High Distraction* (15 ± 8%) compared to *Poor Terrain* (6 ± 7%) and *Intersection* (5 ± 5%). There was no significant difference between *Poor Terrain* and *Intersection*.

Static hazard

The scenario had a significant main effect on relative number of dwells at *Static Hazard* ($p < .001$, $\eta_p^2 = 0.62$). Participants made significantly more dwells at *Static Hazard* in *High Distraction* (15 ± 9%) compared to *Poor Terrain* (3 ± 4%) and *Intersection* (5 ± 4%). There was no significant difference between *Poor Terrain* and *Intersection*.

Path users

The scenario had a significant main effect on the relative number of dwells at *Path users* ($p = .002$, $\eta_p^2 = 0.39$). Participants made significantly more dwells at *Path users* in the *High Distraction* (11 ± 6%) compared to *Poor Terrain* (1 ± 2%) and *Intersection* (5 ± 6%). There was no significant difference between *Poor Terrain* and *Intersection* See Table 2.

3.4. Relative dwell time on each AOI

Total path

The scenario had a significant main effect on dwell time at *Total Path* ($p < .001$, $\eta_p^2 = 0.62$). Participants looked for longer at *Total Path* in the *Poor Terrain* (70 ± 22%) compared to both *High Distraction* (29 ± 13%) and *Intersection* (53 ± 17%). There was a significant increase in the length of dwell at *Total Path* in the *Intersection* compared to *High Distraction* scenario.

Near path

There was no significant main effect of scenario on dwell time at *Near path* ($p > .05$, $\eta_p^2 = 0.05$). Participants looked at *Near path* 4 ± 4%, 6 ± 8% and 7 ± 12% in *High Distraction, Intersection* and *Poor Terrain*, respectively.

Path

The scenario had a significant main effect on dwell time at the *Path* ($p = .02$, $\eta_p^2 = 0.26$). Participants looked for longer at the path in the *Intersection* (36 ± 15%) compared to *Poor Terrain* (19 ± 14%) and *High Distraction* (24 ± 14%). There was no significant difference between *Poor Terrain* and *High Distraction*.

Pot hole

The scenario had a significant main effect on length of fixation at *Pot hole* ($p < .001$, $\eta_p^2 = 0.77$). Participants looked for longer at *Pot hole* in the *Poor Terrain* (44 ± 21%) compared to both *High Distraction* (1 ± 2%) and *Intersection* (11 ± 6%). Participants looked for longer at *Pot hole* in the *Intersection* compared to *High Distraction*.

Side

The scenario had a significant main effect on length of dwell at *Side* ($p = .01$, $\eta_p^2 = 0.30$). Participants looked for longer at *Side* in the *Poor Terrain* (13 ± 13%) and *Intersection* (16 ± 12%) compared to *High Distraction* (4 ± 4%).

Foe

There was no significant main effect of scenario on length of dwell on the *FOE* ($p > .05$, $\eta_p^2 = 0.03$). Participants looked at *FOE* 2 ± 2%, 3 ± 4% and 2 ± 5% in *High Distraction, Intersection* and *Poor Terrain*, respectively.

Distraction

The scenario had a significant main effect on the length of dwell at *Distraction* ($p < .001$, $\eta_p^2 = 0.56$). Participants looked longer at *Distraction* in the *High Distraction* (28 ± 20%) compared to *Poor Terrain* (6 ± 9%) and *Intersection* (7 ± 9%). There was no significant difference between *Poor Terrain* and *Intersection*.

Static hazard

The scenario had a significant main effect on length of dwell at *Static Hazard* ($p = .002$, $\eta_p^2 = 0.39$). Participants looked longer at *Static Hazard* in the *High Distraction* (14 ± 12%) and *Intersection* (6 ± 7%) compared to *Poor Terrain* (1 ± 1%) scenario. There was no significant difference between *High Distraction* and *Intersection*.

Path users

There was no significant main effect of scenario on length of dwell at *Path users* ($p > .05$, $\eta_p^2 = 0.16$). Participants looked at *Path users* in the *High Distraction*, *Poor Terrain* and *Intersection* 12 ± 8%, 3 ± 7% and 8 ± 7%, respectively See Table 2.

Table 2
Visual search behaviour at each area of interest in the three scenarios.

Variable	High Distraction	Intersection	Poor Terrain
Time (sec)	20 ± 3[F,T]	18 ± 3[T]	8 ± 2
Entropy (bits)	1.3 ± 0.4	1.3 ± 0.3	0.8 ± 0.4[D,F]
Number of transitions (nr)	48 ± 17	46 ± 11	16 ± 5[D,F]
Relative number of dwells			
Total Path (%)	33 ± 11	47 ± 12[D]	58 ± 15[D,F]
Near path (%)	7 ± 5	8 ± 7	5 ± 5
Path (%)	25 ± 6	31 ± 7	24 ± 14
Pothole (%)	1 ± 1	8 ± 4[D]	29 ± 11[D,F]
Side (%)	7 ± 6	21 ± 7[D]	15 ± 9[D]
FOE (%)	4 ± 3	6 ± 6	5 ± 10
Distraction (%)	15 ± 8 [F,T]	5 ± 5	6 ± 7
Static hazard (%)	15 ± 9 [F,T]	5 ± 4	3 ± 4
Path users (%)	11 ± 6 [F,T]	5 ± 6	1 ± 2
Relative dwell time			
Total Path (%)	29 ± 13	53 ± 17[D]	70 ± 22[D, F]
Near path (%)	4 ± 4	6 ± 8	7 ± 12
Path (%)	24 ± 14	36 ± 15[D,T]	19 ± 14
Pothole (%)	1 ± 2	11 ± 6[D]	44 ± 21[D,F]
Side (%)	4 ± 4	16 ± 12[D]	13 ± 13[D]
FOE (%)	2 ± 2	3 ± 4	2 ± 5
Distraction (%)	28 ± 20[F,T]	7 ± 9	6 ± 9
Static hazard (%)	14 ± 12 [T]	6 ± 7 [T]	1 ± 1
Path users (%)	12 ± 8	8 ± 7	3 ± 7

Significant differences between scenarios.
[D] High Distraction,
[F] Intersection and,
[T] Poor Terrain.

4. Discussion

The aim of the current study was to investigate the distribution of visual search behaviour of young children when cycling in a naturalistic environment. To examine this we compared three distinct scenarios; cycling in an environment with a large number of distractors (*high distraction)*, cycling up to a fork in the road (*intersection*) and cycling along poor road surface (*poor terrain*). Findings are discussed in terms of the adopted visual search behaviour in this naturalistic environment.

4.1. Where do young cyclist predominantly look when cycling?

In contrast to the motor driving literature, where adult drivers predominantly focus in the distance (e.g., FOE, Lappi, Rinkkala, & Pekkanen, 2017), the young cyclists in the current study spent the highest proportion of time looking at the path (see Fig. 4), an area much closer to the cyclist compared to the FOE. Drivers look at the FOE to acquire advance information used for anticipatory control (e.g., road geometry, Lappi et al., 2017), relying on peripheral vision to monitor the near road (Summala, Nieminen, & Punto, 1996) and utilise discrete fixations / scanning of the closer environment to identify unpredictable features required for compensatory control (Lappi et al., 2017). In contrast, when cycling, it is likely that the speed at which the cyclist was travelling meant that looking at the FOE was too distant to provide relevant information to inform motor planning to adapt cycling behaviour. In support of this supposition, when cycling around a bend, at a slow speed (8 km/hr) adults fixate up to 3–4 m ahead, increasing to look further ahead when cycling at faster speeds (Vansteenkiste et al., 2013). Additionally, the three scenarios analysed all contained overt (potholes, gravel) or covert (i.e., blind bend) hazards, requiring that vision is orientated upon near distance to these overt and convert hazards within their functional approach space (c.f. Laurent & Thomson, 1991; Pelz & Rothkopf, 2007, chap. 31). Although vision was predominantly orientated at the ground, cyclists distributed gaze throughout the visual scene, across multiple areas of interest. Hence, continuous visual monitoring of the road/path is not necessary for safe and efficient cycling, demonstrating that both adults and children are able to successfully allocate cognitive resources over multiple areas within the environment when cycling (Vansteenkiste et al., 2017, 2013, 2014). This finding also highlights that the peripheral visual field plays an important role for guidance not only in adults (Ahlstrom, Kircher, Thorslund, & Adell, 2016) but also in children when cycling. Importantly, as the peripheral visual field provides poorer resolution of fine detail (visual acuity, Mandelbaum & Sloan, 1947) and spatial modulation sensitivity (Hilz & Cavonius, 1974) compared to central vision, when path terrain deteriorated (i.e. *poor terrain* scenario), reorientation of gaze was required to look directly at the path, specifically towards the pot holes. Indeed, the entropy analysis supports this suggestion. Within the poor terrain scenario, both entropy and the number of transitions were significantly lower than in high distraction and intersection scenarios. This highlights that the young cyclists successfully adapted their acquisition of visual information to account for changes in these overt hazards in the environment. Confirming our hypothesis and supporting the findings from Vansteenkiste et al. (2017) it was identified that both the relative number of dwells and the relative time looking at the path, including potholes, (i.e., 58% and 70% respectively) was significant greater in the poor terrain scenario compared to the two other scenarios. This highlights that the young cyclists prioritised acquiring detailed visual information of the condition of the path and potholes to adjust their cycling behaviour accordingly. In addition to the increased length of time spent looking at potholes in *poor terrain* compared to *high distraction* scenario, there was also an increase in the frequency looking at the potholes (29% compared to 1% total frequency of dwells in *poor terrain* and *high distraction* respectively). The increased time spent looking at the potholes would have allowed precise visual information to be acquired regarding the terrain's characteristics whereas the increased frequency reflected the need to reorientate gaze to different areas either within the same pothole or towards other potholes, for reasons mentioned previously. Reorientation of gaze behaviour towards the ground when cycling on poor terrain has been previously suggested as the need to make more steering adjustments to avoid cycling through undesirable locations and ensure stability/balance on the bike is maintained (Vansteenkiste et al., 2013). It has also been suggested that since the surface of a lower quality terrain is more rugged, it is more visually salient and serves to attract attention (Vansteenkiste et al., 2014).

4.2. Distractions within the environment

The entropy analysis confirmed our hypothesis that visual search behaviour becomes less predictable when cycling in an environment with a large number of distractions. A significantly higher entropy and number of transitions in the *high distraction* scenario confirmed that the available relevant and irrelevant information in this scenario affected visual search behaviour. The high distraction scenario was characterised by an adventure playground, confined behind metal railings, which had little ability to directly influence the cyclist's behaviour (i.e., a person could not suddenly appear in the cyclist's path). The increased saliency / relative distractibility of the people (who were running, jumping etc.) and the bright coloured playing equipment in the adventure playground attracted the attention of the cyclists (see Table 2). Confirming our hypothesis, the high distraction scenario was characterised by a significant increase in the relative number of dwells and dwell time at distractions and static hazards compared to other scenarios. Concurrently, the relative number of dwells and dwell time towards the direction of travel (i.e., path) significantly reduced. Visually inspecting task irrelevant areas within the environment is a relatively common occurrence when the mental load required to complete the task is low (Igari et al., 2008) as there is visual 'spare capacity' (Ahlstrom et al., 2016) to engage in other tasks which may occur for the purpose of entertainment (Turano, Geruschat, Baker, Stahl, & Shapiro, 2001 e.g., identifying appealing play equipment in the adventure playground). However, what remains uncertain from the present research is whether the cyclists were looking in the adventure playground due to the relative low mental load occurring from the task, or if they were being distracted by this area. The ability to 'resist' looking at task irrelevant areas poses an important factor for cycling safety. Research has demonstrated how children become more strategically-focused on relevant features within the environment as they mature (Day, 1975) which is a result of their still developing situation awareness (c.f. Endsley, 1995). Indeed, as children mature, they develop an increased understanding of the environment and are better able to pay attention to relevant information while ignoring irrelevant information. Within the current study this reflected a change in visual search behaviour towards path users in the high distraction scenario. Whilst there was no significant difference in the relative time looking at the path users (See Table 2), participants increased the frequency of looking at the path users. This visual behaviour is reminiscent of a 'checking strategy', affording cyclists the ability to identify the location of other path users within the environment without the expense of reducing the time looking at other task relevant and distracting information. An additional analysis of the timing of this 'checking strategy' of path users was run from the time of the first dwell at path users to passing the path users in the high distraction scenario in comparison to other situations where the participants encountered a path user. There was no significant difference between the total time from the first gaze at the path user, to passing the path user in the high distraction scenario (10.0 ± 5.3 s) compared to other situations where participants encountered path users (11.3 ± 5.3 s, $t(11) = 0.56$, $p > .05$). This suggests that the young cyclists successfully adapted their visual search behaviour (i.e., increased scan rate at path users) without sacrificing their ability to acquire early visual information of these potentially hazardous path users within this high distracting environment. This increase of scanning behaviour is important for cyclists within this distracting environment as hazards may suddenly appear in the environment or path users might change direction which allows the cyclist time to plan/initiate a suitable avoidance response (see Patla & Rietdyk, 1993; Patla, 1998; Patla & Greig, 2006 for related discussion in walking gait).

4.3. Limitations

The study was completed in a naturalistic environment that reduced the opportunities to systematically control the occurrence of hazards and distractors within the environment. Although the selection of distinct scenarios identified clear differences in the adopted visual search behaviours, it would be of interest in future research to examine, in a more controlled set up (e.g., in a virtual environment), how mental load, hazard identification and distractions influence visual search and cycling behaviour.

This set up would also allow for the examination of visual search behaviour of children when cycling on the roads, in the presence of car drivers, alleviating some of the ethical and practical risks of conducting this in a naturalistic environment. Although our sample size allowed for the examination of differences in visual search behaviour across scenarios, we were unable to analyse the effect of expertise, despite variation in visual search behaviour. Both age, affecting cognitive development and hazard perception, and differences in exposure to cycling (cycling to school on the road or pavement and leisure cycling) creates a complex interaction to define cycling experience in children. We recommend future research to examine how we can define cycling expertise in children, including elements of cognitive and motor development, age and exposure to cycling. The limitation with using the eye tracker is the assumption that people are attending to where they are looking. Whilst visual attention and eye movements are closely related, research has shown that it is possible to 'shift' our attention without moving our eyes (Posner, 1980); cyclists may not be perceiving information from the precise location where they are looking. However, research has shown that it is more efficient to move our eyes than move attention (Peiyuan & Kowler, 1992) and that eye movements and visual attention are linked in most instances (Koch & Itti, 2001).

5. Summary

The study provides a valuable insight into the visual search behaviour of young cyclists in an urban environment. Young cyclists successfully adapt their visual search behaviour dependent upon the situations they encounter. A high distraction scenario attracted the attention of the young cyclists, resulting in a reduction of time attending to the direction of travel. Whilst this reduced their ability to spot new hazards within this environment, they increased visual scanning of overt hazards (i.e., path users) to update and monitor their positioning. Whilst cycling through *Poor terrain* a significant increase in the time looking down at the pot holes was identified, presumably to identify the hazardous road surface to alter cycling behaviour. This resulted in a much more predictable (i.e. less random) visual search behaviour, which was directed at the floor and influenced the cyclists ability acquire visual information from the environment. To maximise cycling safety afforded to children when cycling, ensuring they have sufficient opportunity to look around when cycling, being able to identify potential dangers / hazards, town planners must consider the implications of not sufficiently maintaining cycle path terrain and the use of shared (i.e., pedestrian/cyclist) paths in urban environment and distracting environments.

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Appendix A

(see Fig. B1)

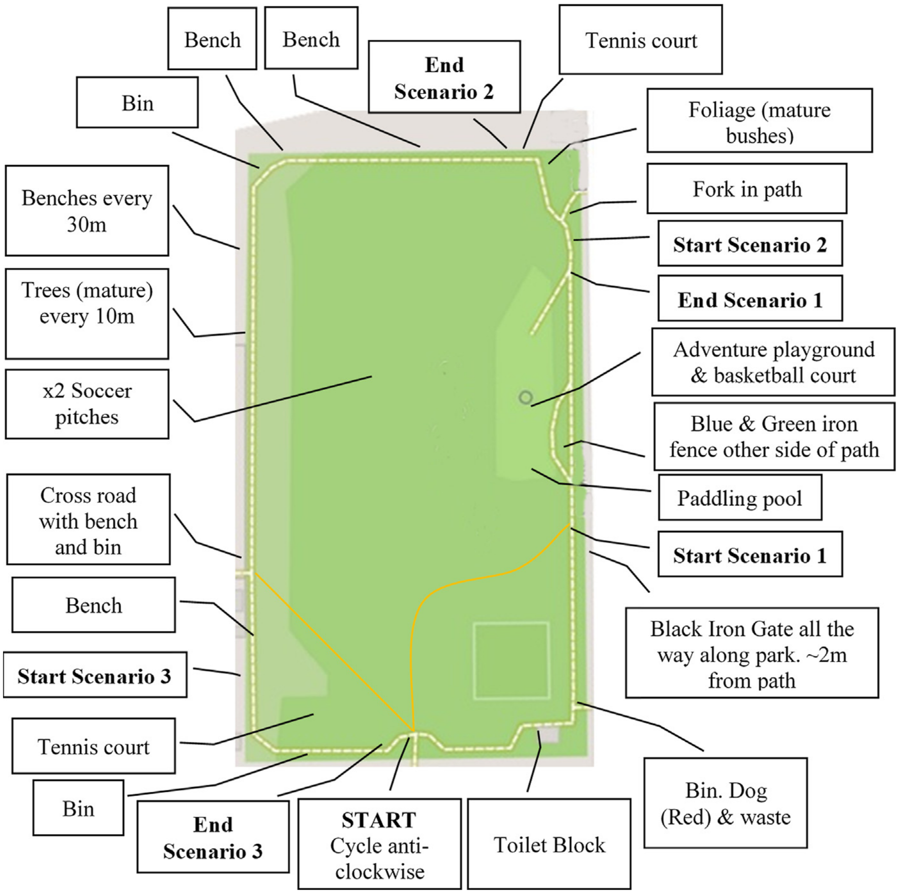

Fig. B1. Illustration of the recreational ground. Children were asked to cycle anti-clockwise, along the yellow dashed line, completing two consecutive laps of the recreation ground.

(see Table A1)

Table A1
Participant descriptive information and cycling behaviour.

Part.	Age (yrs)	Duration without stabilisers (months)	Cycle to school	Typical no. days cycle to school	Duration school cycle (mins)	Last seven days				
						Days cycled	Total no. trips	To and from school	Accidents past month	Accidents past year
1	8	40	Yes	5	8	7	14	5	0	0
2	8	69	Yes	5	9	6	14	10	0	1
3	7	49	Yes	5	9	6	14	10	1	3
4	10	82	Yes	2	5	4	10	4	0	1
5	9	55	Yes	5	5	5	15	10	0	0
6	7	42	Yes	5	10	6	16	10	0	2
7	9	53	Yes	5	10	6	16	10	0	1
8	7	42	Yes	5	11	6	12	10	0	2
9	5	10	Yes	5	11	6	12	10	1	3
10	9	67	Yes	1	7	4	6	0	0	1
11	7	48	No	0	0	0	0	0	0	0
12	9	67	No	0	0	0	0	0	0	0
13	7	43	Yes	3	15	5	8	8	0	2
14	7	39	No	0	0	1	2	0	0	0

NB. Accident was defined as unintentionally falling off the bike.

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2019.10.014.

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