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Understanding Visual Engagement with Urban Street Edges along Non-Pedestrianised and Pedestrianised Streets Using Mobile Eye-Tracking

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Abstract: Existing knowledge of street edge experience has often been constructed using methods that offer a limited opportunity to gain empirical insight from the first-hand perspective of pedestrians. In order to address this, mobile eye-tracking glasses were used during the current investigation to provide a detailed understanding of pedestrian visual engagement with street edges along both non-pedestrianised and pedestrianised urban streets. Through this, the current study advances empirical knowledge of street edge experience from a perspective that has previously been challenging to capture and quantify. The findings demonstrate that people visually engage with street edge ground floors more than their upper floors, that visual engagement is distributed more towards the street edge on the walked side of non-pedestrianised streets than the opposite side, and that visual engagement with street edges of pedestrianised streets is balanced across both sides. The study findings also highlight how the everyday activities of pedestrians and different streets being walked often influence the amount of visual engagement within these street edge areas. These insights provide a new understanding that develops existing knowledge of pedestrian street edge experience. Significantly, they also provide an empirical foundation from which to examine how design intervention can become more considerate of peoples' routine use of and experiential engagement with street edges along non-pedestrianised and pedestrianised urban streets.

Keywords: street edge; visual engagement; mobile eye-tracking; ground floors; pedestrian streets; non-pedestrianised streets

1. Introduction

Street edges span the interface between indoor and outdoor realms along urban streets. It has been argued that they significantly impact the everyday pedestrian experience [1–3]. Understanding the nature of such experience is important against a backdrop of contemporary issues, such as high street decline [4–6] and the reduction in the variety of street edge functions [7–9]. These factors have impacted how experientially engaging and stimulating today's street edges are for pedestrians, subsequently reducing their capacity to positively influence peoples' day-to-day quality of life [10–12]. Even though this is understood, there still remains a limited systematic understanding of the general principles that characterise the way in which people visually engage with street edges [3,13,14]. This makes it challenging to guide socially and experientially responsive street edge design intervention. The current investigation addresses this lack of first-hand empirical insight through the use of mobile eye-tracking. Specifically, it assesses the extent to which pedestrians visually engage with street edge ground and upper floors, as well as street edges on different sides of non-pedestrianised and pedestrianised streets. To provide greater insight, it also examines how optional and necessary pedestrian activities and

differing streets walked influence the amount of visual engagement with these street edge areas. Through this study, the current investigation provides a highly detailed insight into peoples' visual engagement with street edges from a pedestrian perspective that has previously been challenging to capture and comprehend. The findings obtained are then used to explore how design decision-making can become more considerate of peoples' routine experiential engagement with street edges.

Over many years, an understanding of what visual qualities and attributes of environmental scenes people engage with and value has been attained, often with a focus towards influencing design decision-making [15–18]. Alongside this, new data collection methods have provided a greater opportunity to capture insight into how these environments are engaged with by people while they are immersed within them [19–21]. However, even though advancements have been made, the application of new techniques to the systematic assessment of how pedestrians visually engage with urban street edges remains limited. To date, existing knowledge of street edge experience has often been attained through observations and interviews [22,23]. Interviews require the verbalisation of often difficult to describe and regularly fleeting experiences [24]. Observations regularly focus upon overt human–environment interactions and are susceptible to observer bias [25]. As a result, these methods often restrict the opportunity for individual experiential influences to be systematically analysed. This is significant when reflecting upon calls for built environment design intervention to become more evidence-based through an empirical understanding of peoples' routine use and engagement with urban environments [26–28]. In order to overcome these methodological issues, mobile eye-tracking glasses are used during the current investigation. This data collection technique captures quantified information on gaze distribution, through tracking eye-movements, allowing a detailed understanding of specific influences on cognition and perception [29]. Recently, there have been a number of mobile eye-tracking studies in outdoor urban situations [14,21,30], as well as indoor eye-tracking studies that assess how people distribute their gaze upon images of urban settings [31–33]. This highlights a steady increase in the number of eye-tracking studies assessing how people visually engage with various urban stimuli. However, none of these studies have so far sought to use eye-tracking in real-world situations to investigate which areas of street edges people visually engage with along non-pedestrianised and pedestrianised streets. Such an assessment is undertaken during the current investigation, with the information captured providing empirical insight that develops existing understandings from a direct pedestrian perspective.

1.1. Visual Engagement with Street Edge Ground and Upper Floors

It has been argued that pedestrians predominantly engage with street edge ground floors in comparison to upper floors [34,35]. For Gehl [1], ground floors are a key feature of a successful *city at eye level*. Glaser et al. [2], in an attempt to quantify ground floor experiential significance, claim that "*the ground floor may only be 10% of a building, but it determines 90% of the building's contribution to the experience of the environment*" (p. 12). From this assertion, they propose the concept of *street plinths*, with the re-appropriated use of the term *plinth* aiming to refocus attention upon ground floor social and experiential significance. Related to this is the proposition that street edges need to be understood across multiple scales [2,36,37]. Through this, there has been the opportunity to consider ground floors as being distinctly scale embedded within the wider built morphology of street edges [2,34,38]. This again highlights an attempt to focus attention upon ground floor significance, as well as to provide a greater chance for design decision-making actions to be more considerate of their specific requirements in response to peoples' engagement with them [2,38,39]. However, across the ideas introduced, there is a lack of empirical insight, from the first-hand experiential perspective of pedestrians, that evidences the arguments made. The current investigation will address this through a systematic assessment of pedestrian visual engagement with street edges using mobile eye-tracking.

Building upon the points made, little is known about the way that streets, spanning both different non-pedestrianised and pedestrianised streets, influence the extent to which visual engagement is predominantly focused upon street edge ground floors. Previous mobile eye-tracking research has

highlighted that pedestrians visually engage with the totality of surrounding street edges to variable extents along different streets [14]. However, it is not fully understood if this insight is transferable when considering ground floors along differing non-pedestrianised and differing pedestrianised streets. Currently, there is also limited knowledge of the way in which variable pedestrian activities within streets influence ground floor visual engagement. There has recently been a growing understanding that people are situated and embodied agents experiencing their surroundings in an enactive manner that is responsive to variable social and spatial influences [40,41]. However, the extent to which specific social factors, such as varying everyday activities, influence street edge and specifically ground floor engagement is still not fully understood. Previous research has highlighted how contrasting activities affect how people behave in urban settings, providing opportunity to categorise peoples' everyday actions into optional and necessary activities [1]. Mobile eye-tracking has subsequently shown how these activity groups influence wider street edge visual engagement [14]. However, no studies have focused on examining the impact that these pedestrian activities have upon ground floor visual engagement along non-pedestrianised and pedestrianised streets. From these foundations, the current investigation asks the following:

Research Question 1a: Do people visually engage with street edge ground floors more than upper floors along (i) non-pedestrianised and (ii) pedestrianised streets? 1b: Do different everyday activities and different streets walked influence the amount of visual engagement upon street edge ground floors along (i) non-pedestrianised and (ii) pedestrianised streets?

Existing discourse provides an opportunity to hypothesise that pedestrians will visually engage more with street edge ground floors compared to upper floors along both non-pedestrianised and pedestrianised streets, [1,2,34,35]. Building upon previous eye-tracking research, that was not ground floor specific and did not systematically assess differences across non-pedestrianised and pedestrianised streets [14], it is anticipated that everyday activities and differing streets walked will influence the amount with which ground floors are visually engaged.

1.2. Visual Engagement with Street Edges on Different Sides of the Same Street

It has been suggested that pedestrians engage with street edges on opposing sides of a street differently [1,34,37]. Along non-pedestrianised streets, the street edge on the walked side is experienced at a closer, more-detailed range and as a result, is able to capture and hold pedestrian engagement to a greater extent. The opposite street edge cannot be engaged as closely and objects in the street often hinder prolonged engagement. Even though this is understood, there is limited empirical evidence from a pedestrian perspective highlighting the disparity in engagement between the walked and opposite side street edges of the same non-pedestrianised street. Street edges along pedestrianised streets cannot be delineated as walked and opposite, with pedestrians often able to occupy much more of the street space between the edges [42,43]. These street edges are instead left and right sided from a pedestrian perspective. Significantly, we currently lack empirical knowledge of the way in which these street edges of the same pedestrianised streets are visually engaged with. Similar to understandings of ground floor visual engagement, it is currently not known how visual engagement with street edges on different sides of non-pedestrianised and pedestrianised streets varies in response to everyday pedestrian activities and different streets walked. The current investigation will use mobile eye-tracking to address the lack of knowledge in this area, while asking the following:

Research Question 2a: Are there differences in the amount of visual engagement upon street edges on different sides of the street along (i) non-pedestrianised and (ii) pedestrianised streets? 2b: Do different everyday activities and streets walked influence the amount of visual engagement upon street edges on different sides of the street along (i) non-pedestrianised and (ii) pedestrianised streets?

It is predicted that visual engagement will be focused towards the street edge on the walked side of non-pedestrianised streets [1,34,37]. In contrast, visual engagement with street edges of pedestrianised streets will be more balanced across both sides. Building upon the understanding that differing activities and streets walked impact street edge visual engagement overall [14], it is predicted that

such factors will also influence the amount that street edges on the walked and opposite sides of non-pedestrianised streets, as well as edges on the left and right sides of pedestrianised streets, are visually engaged with.

1.3. The Influence of Pedestrianisation upon Visual Engagement with Urban Street Edge Areas

The broad benefits of pedestrianisation have been detailed by many [1,35,42,43]. However, it is not understood how such intervention impacts pedestrian engagement with street edges. Specifically, there has been no systematic exploration of how visual engagement with areas of street edges along pedestrianised streets contrasts with that of street edges areas of non-pedestrianised streets. Therefore, the current investigation asks the following:

Research Question 3: Are there differences in the amount of visual engagement upon (i) street edge ground floors between non-pedestrianised and pedestrianised streets, and (ii) street edge sides between non-pedestrianised and pedestrianised streets?

The experiential significance of street edge ground floors has been described, often regardless of context [1,2,34]. It is therefore hypothesised that there will be no significant difference in the amount of visual engagement with ground floors between non-pedestrianised and pedestrianised streets. It is anticipated that visual engagement will be more balanced across both street edges of pedestrianised streets, in contrast to non-pedestrianised streets, where it will be focused on the edge on the walked side [1,34,37]. This provides the opportunity to hypothesise that there will be a noticeable difference in the amount of visual engagement upon the different street edge sides between non-pedestrianised and pedestrianised streets.

2. Materials and Methods

2.1. Participants

Opportunity sampling, through a volunteers list held by the University of Sheffield, was used to recruit 24 adult study participants (n = 12 female; n = 12 male) with a mean age of 35 years (range = 21–61 years, standard deviation = 10). Academic staff were omitted from invitation to attain a sample without bias towards higher education levels. All participants had normal to corrected-to-normal vision via contact lenses, did not know the intentions of the study at the time of participation, and had previous experience of the streets investigated.

2.2. Apparatus

A SensoMotoric Instruments (SMI) Glasses 2.0 Mobile Eye-tracker was used within the current investigation. Inside the frame of these glasses are one forward-facing camera recording a video of the environment in front of the wearer and two backward-facing cameras in the rim of the glasses recording the wearer's eye movements. The video data captured was processed using SMI BeGaze to give a single video output, comprising the video of the environment in front of the wearer with the gaze location superimposed on top. Each participant was fitted with the mobile eye-tracker and wore a peaked cap to help limit the influence of sunlight on data quality, which is consistent with previous real-world eye-tracking studies [44].

2.3. Design

The current study examined the percentage of pedestrian visual engagement with different urban street edge areas of interest (AOIs). These AOIs were ground and upper floors along non-pedestrianised streets (Figure 1A), ground and upper floors along pedestrianised streets (Figure 1B), street edges on the walked and opposite side of non-pedestrianised streets (Figure 1C), and street edges on the left and right sides of pedestrianised streets (Figure 1D). The study also examined the effect of two independent variables—street (levels = street id; non-pedestrianised and pedestrianised streets were considered

separately) and pedestrian activity (levels = optional and necessary activities)—on the dependent variable, which was the percentage of visual engagement upon the street edge AOIs discussed.

Non-pedestrianised streets within the current investigation were considered as streets with thoroughfares that actively delineate pedestrian and vehicular movement. Pedestrianised streets comprised a single space that pedestrians have priority of movement and activity within, even though street materiality and furniture may still delineate opportunity for vehicular access.

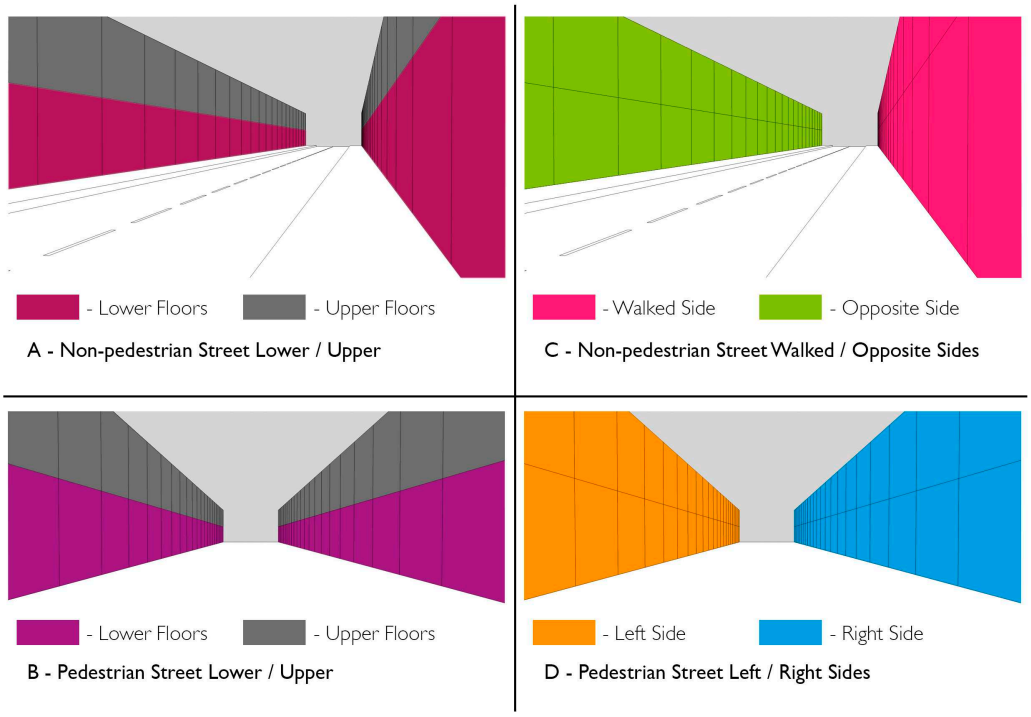

Figure 1. Diagram of Street Edge Areas of Interest (AOIs).

2.4. Procedure

Figure 2 presents an overview of the methodological procedure employed during the current investigation to collect, process and code the mobile eye-tracking data. After fitting the participant with the mobile eye-tracker, a three-point calibration was undertaken. Subsequent checks for tracking accuracy were undertaken and, if required, calibration was repeated. Data collection took place during the day and not at night, as this could have influenced the data captured [45]. It also took place during fair weather conditions in order to reduce the effect of poor weather, such as rainfall, on participant behaviour within the study streets. A cap was worn by the study participant in order to allow data collection within sunny conditions [44].

Two walked routes were used during the current study, with each route comprising six streets within Sheffield's city centre, UK. Following the initial study setup (see Figure 2, points 1–3), participants were requested to walk one of these two routes. The battery-life of the eye-tracker restricted the duration of data collection to six streets per participant, so two routes were used in order to provide eye-tracking data of street edge visual engagement from a range of different streets. Both routes comprised non-pedestrianised and pedestrianised urban streets, were discrete, and were devised so that each street had a well-defined start and end point. This was in order to reduce the need for wayfinding, which may have influenced how participants visually engaged with their surroundings.

Before walking along a street of a specified route, study participants were required to read a task card. This introduced an everyday activity for the participant to undertake when walking that street (see Figure 2, point 4). This process took place for each of the six streets of the route walked and provided the opportunity to assess the extent to which everyday activities impacted the distribution of

visual engagement upon the different street edge AOIs. The activities were derived from the on-site observation of peoples' routine behaviours, establishing a degree of real-world and context-specific validity. In total, six activities were selected across two categories: optional activities (break-time stroll, going for coffee with a friend, window-shopping) and necessary activities (rushing to work, dropping an item off with a friend, walking to the bus). The activities were distributed evenly amongst the streets, with each study participant carrying out an activity once (three optional and three necessary activities across six streets along a single route, see Figure 2, points 4–6).

Data collection across the two routes was undertaken twice; however, eye-tracking data for one street was omitted from the subsequent analyses due to it only having a street edge on one side. This resulted in the data from six non-pedestrianised and five pedestrianised streets being assessed (see Figure 2, points 7–9 and Figure 3 for eye-level images of the study streets). Such a process provided a total dataset of pedestrian visual engagement with the street edges of 132 walked streets, i.e., 24 study participants walking eleven different streets undertaking different activities that were either optional or necessary.

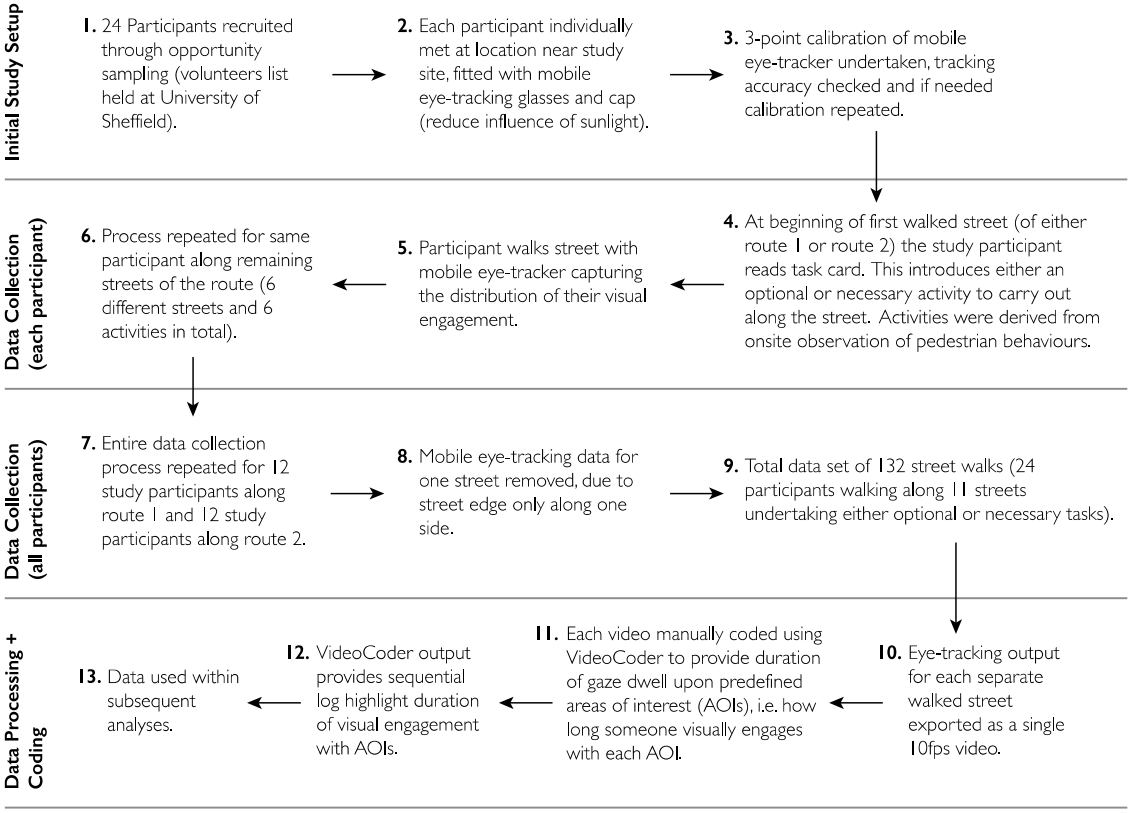

Figure 2. Methods Workflow Diagram.

2.5. Data Processing and Coding

Following the completion of data collection (see Figure 2, points 4–9), each participant's eye-tracking data for each separate street was exported as a single video. VideoCoder [46] was then used to code the gaze dwell duration upon street edge AOIs based upon the knowledge that each video frame indicated the gaze location for a tenth of a second (see Section 2.2 Design for the AOIs used when coding). Processing the data in this way overcame issues with eye-movement definition, with the raw eye-tracking video output being used prior to the automated classification of eye-movements as either fixations (when the eye is stationary and focused upon a stimulus), or saccades (when the eye is moving and re-adjusting itself) [47,48]. After coding, a log of sequential gaze dwell durations on the AOIs was exported, which could then be used within the subsequent analyses. Depending on the

question being posed, these analyses took into account 1) only street edge visual engagement data in order to compare the percentage of visual engagement upon a street edge AOI vs. another street edge AOI (e.g., the amount of visual engagement with ground floors vs. upper floors), or 2) participant visual engagement with the entire street in order to assess the percentage of visual engagement upon a street edge AOI vs. visual engagement with the rest of the street (e.g., the amount of visual engagement with ground floors vs. the entire street).

With tracking accuracy in outdoor investigations being typically lower, when compared with laboratory-based eye-tracking, it was anticipated that there would be fluctuations in the data quality. Data loss was generally low, but did vary slightly, resulting in a mean tracking ratio of 93% (range = 68%–99%, standard deviation = 6%). All data captured and coded was used in the following analyses.

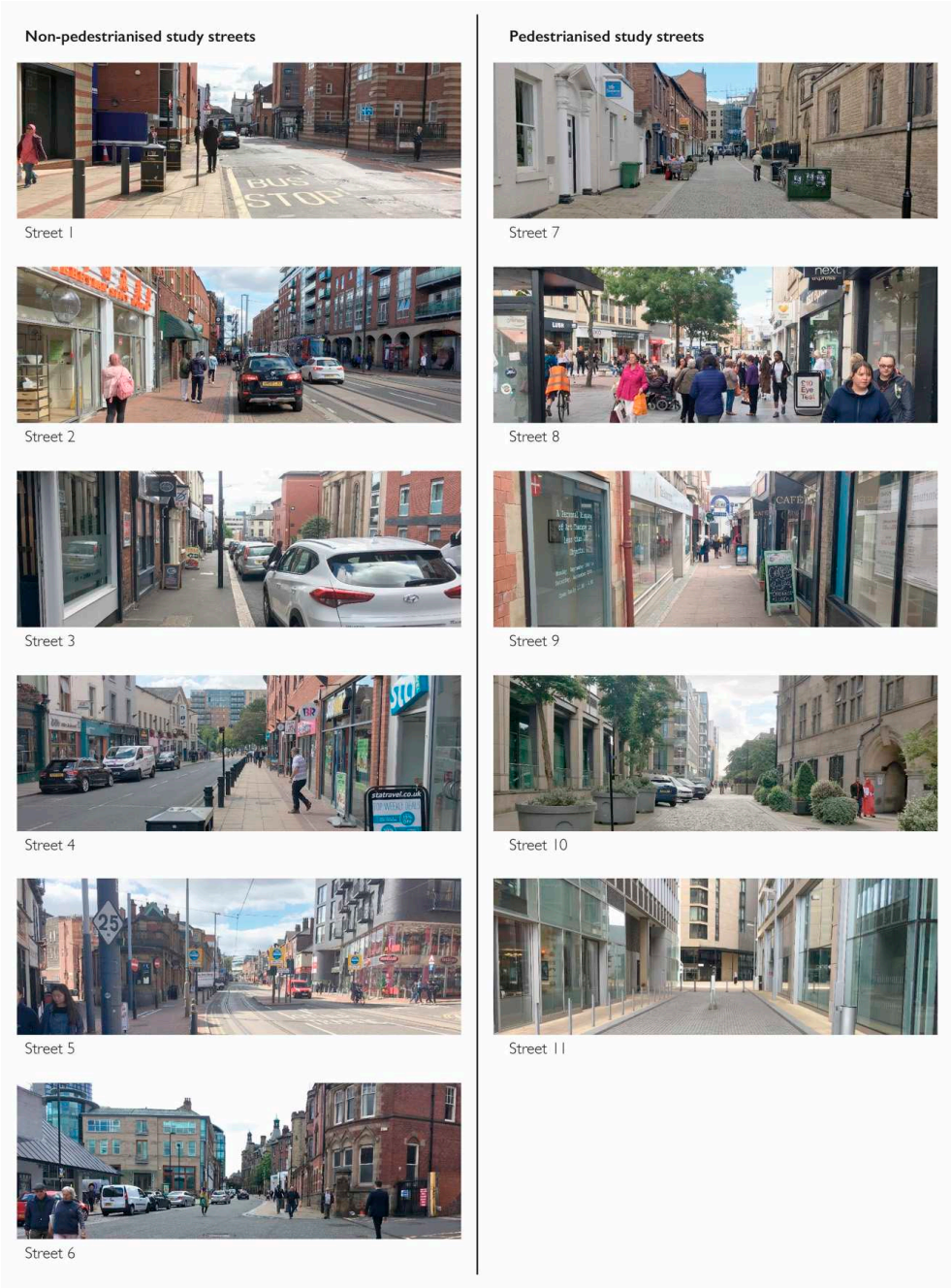

Figure 3. Eye-Level Images of Study Streets.

3. Analysis and Results

3.1. Research Question 1a: Do People Visually Engage with Street Edge Ground Floors more than Upper Floors along (i) Non-Pedestrianised and (ii) Pedestrianised Streets?

To determine if participants visually engaged more with street edge ground or upper floors along both non-pedestrianised and pedestrianised streets, Welch two-sample *t*-tests were performed. This *t*-test was chosen because of unequal variance between the two samples. Visual engagement was focused overwhelmingly upon ground floors in comparison to upper floors along both non-pedestrianised streets and pedestrianised streets (Table 1).

Table 1. The amount of visual engagement with street edge ground and upper floors along non-pedestrianised and pedestrianised streets (mean ± standard error).

Street Type	Amount of Visual Engagement with Street Edge Ground and Upper Floors (Only Street Edge Visual Engagement)			Amount of Visual Engagement with Street Edge Ground and Upper Floors (Entire Street Visual Engagement)		
	Ground Floor	Upper Floors	*t*-Test Results	Ground Floor	Upper Floors	*t*-Test Results
Non-pedestrianised street	90.1% ± 2.0%	9.9% ± 2.0%	t (142) = 46.52, $p < 0.001$	34.2% ± 2.4%	3.6% ± 0.5%	t (78.35) = 12.55, $p < 0.001$
Pedestrianised street	91.7% ± 2.5%,	8.3% ± 2.5%	t (118) = 33.36, $p < 0.001$	34.8% ± 2.8%	2.8% ± 0.5%	t (62.67) = 11.41, $p < 0.001$

3.2. Research Question 1b: Do Different Everyday Activities and Streets Walked Influence the Amount of Visual Engagement upon Ground Floors along (i) Non-Pedestrianised and (ii) Pedestrianised Streets?

The effects of activity and street on participants' visual engagement with street edge ground floors were determined using linear mixed-effects models in the R statistical computing environment [49] ('lme4' package [50]). The fixed effects were 'activity' (optional or necessary) and 'street' (street id: 1–6 for non-pedestrianised and 7–11 for pedestrianised). To account for inter-participant variation in gaze behaviour, 'participant' (participant number 1–24) was entered as a random effect, which allowed different intercepts for each participant (i.e., a differing baseline level of engagement for each participant). *P*-values were simulated by comparing this model to a grand mean model using a parametric bootstrapping method ('pbkrtest' package; [51]) with 10,000 simulated generations. The goodness of fit for all mixed effect models was assessed using the 'R.squaredGLMM' function ('MuMin' package [52]) and marginal R^2 values (those associated with the fixed effects only) were high (non-pedestrianised street analyses: $R^2 = 0.58$, pedestrianised street analyses: $R^2 = 0.55$).

The activity being undertaken influenced the amount of visual engagement with street edge ground floors along both non-pedestrianised (see Figure 4A) and pedestrianised streets (see Figure 4B) (Table 2). The different streets walked influenced the amount of visual engagement with street edge ground floors along both non-pedestrianised (see Figure 4B) and pedestrianised streets (see Figure 4D) (Table 2).

Table 2. The influence of everyday activities and street walked upon visual engagement with street edge ground floors along non-pedestrianised and pedestrianised streets (mean ± standard error).

Street Type	Amount of Visual Engagement with Ground Floors when Undertaking Different Activities (Entire Street Visual Engagement)			Amount of Visual Engagement with Ground Floors along Different Streets (Entire Street Visual Engagement)	
	Optional Activity	Necessary Activity	LRT Result	Streets Walked (Range)	LRT Result
Non-pedestrianised street	46.2% ± 3.2%	22.1% ± 2.2%	46.49, $p < 0.001$	19.9% ± 3.0% 50.0% ± 7.4%	35.02, $p < 0.001$
Pedestrianised street	44.2% ± 4.1%	25.5% ± 2.9%	23.87, $p < 0.001$	15.7% ± 3.1% 56.7% ± 5.1%	40.15, $p < 0.001$

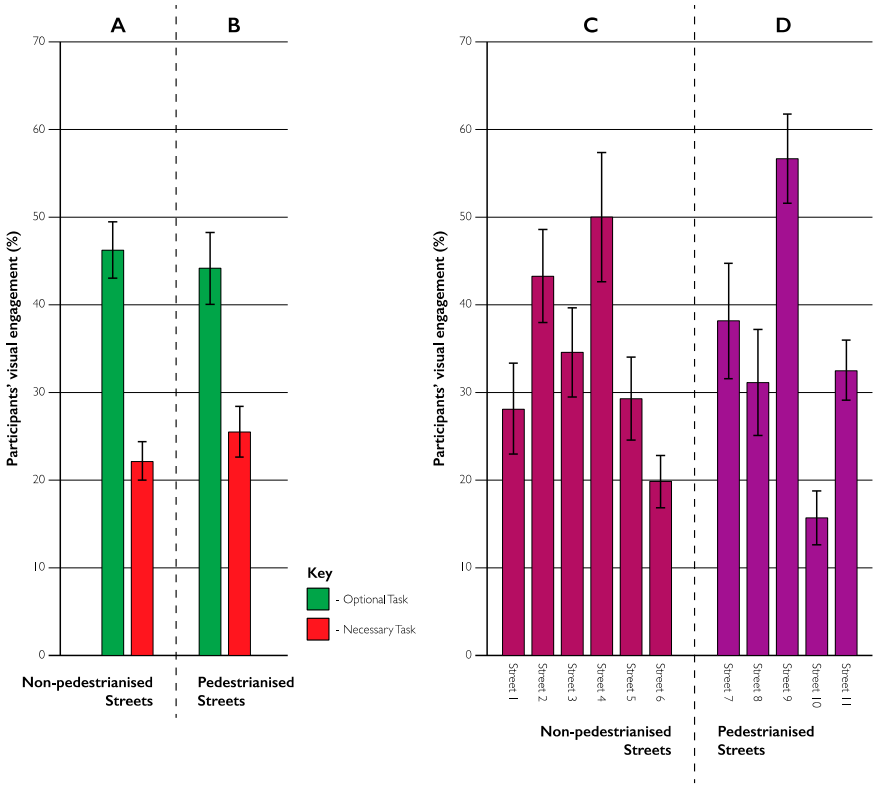

Figure 4. The influence of activity and street on the percentage of participants' visual engagement with street edge ground floors along non-pedestrianised and pedestrianised streets. Error bars represent 1 standard error.

3.3. Research Question 2a: Are there Differences in the Amount of Visual Engagement upon Street Edges on Different Sides of the Street along (i) Non-Pedestrianised and (ii) Pedestrianised Streets?

To determine if the amount of participant visual engagement with the different sided street edges varied along both non-pedestrianised and pedestrianised streets, Welch two-sample *t*-tests were performed. Visual engagement with street edges along non-pedestrianised streets was predominantly with the street edge on the walked compared with the opposite side (see Table 3a). The amount of visual engagement with street edges along pedestrianised streets did not vary across the street edges on the left and right sides (see Table 3b).

Table 3. (**a**) The amount of visual engagement with street edges on different sides of non-pedestrianised streets (mean ± standard error). (**b**) The amount of visual engagement with street edges on different sides of pedestrianised streets (mean ± standard error).

(**a**)						
Street Type	**Amount of Visual Engagement with Different Sided Street Edges (Only Street Edge Visual Engagement)**			**Amount of Visual Engagement with Different Sided Street Edges (Entire Street Visual Engagement)**		
	Walked Side	**Opposite Side**	***t*-Test Result**	**Walked Side**	**Opposite Side**	***t*-Test Result**
Non-pedestrianised street	72.1% ± 3.5%	27.9% ± 3.5%	t (142) = 15.14, $p < 0.001$	27.8% ± 2.2%	10.0% ± 0.9%	t (96.13) = 7.45, $p < 0.001$

Table 3. *Cont.*

(b)						
Street Type	**Amount of Visual Engagement with Different Sided Street Edges (Only Street Edge Visual Engagement)**			**Amount of Visual Engagement with Different Sided Street Edges (Entire Street Visual Engagement)**		
	Left Side	**Right Side**	***t*-Test Result**	**Left Side**	**Right Side**	***t*-Test Result**
Pedestrianised street	51.0% ± 4.2%	49.0% ± 4.2%	t (118) = 0.49, p = 0.62	19.9% ± 1.9%	18.0% ± 1.6%	t (114.61) = 0.75, p = 0.45

3.4. Research Question 2b: Do Different Everyday Activities and Streets Walked Influence the Amount of Visual Engagement upon Street Edges on Different Sides of the Street along (i) Non-Pedestrianised and (ii) Pedestrianised Streets?

To determine the effect of activity and street, linear mixed-effects models were again fitted to the data. The fixed effects were activity and street, with participant as a random effect. Marginal R^2 values (those associated with the fixed effects only) were high (analyses for walked non-pedestrianised edge $R^2 = 0.54$; opposite non-pedestrianised edge $R^2 = 0.25$; left side pedestrianised edge $R^2 = 0.33$; right side pedestrianised edge $R^2 = 0.39$).

The activity undertaken influenced the amount of visual engagement with both the street edges on the walked and opposite sides of non-pedestrianised streets (see Figure 5A and Table 4). Along pedestrianised streets, activity influenced the amount of visual engagement with both the street edge on the left and right sides (see Figure 5B and Table 4).

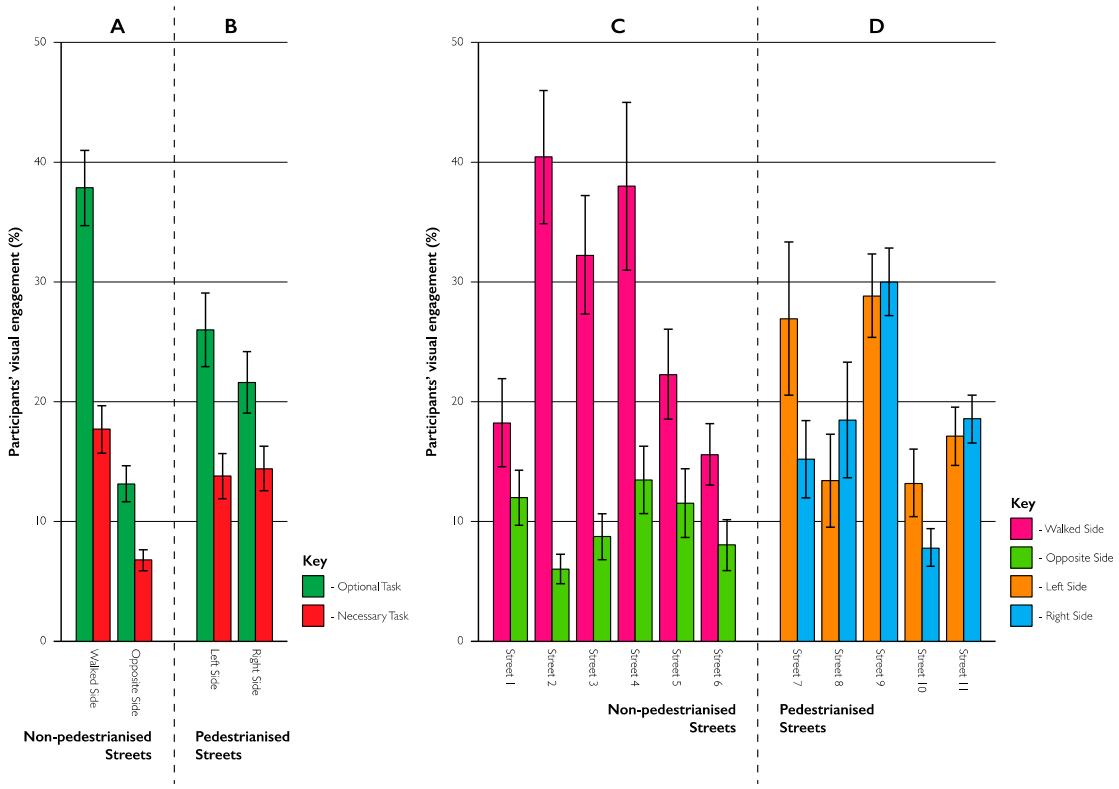

Figure 5. The influence of activity and street on the percentage of participants' visual engagement with street edges on different sides along non-pedestrianised and pedestrianised streets. Error bars represent 1 standard error.

Table 4. The influence of everyday activities and street walked upon visual engagement with street edges on different sides of the street along non-pedestrianised and pedestrianised streets (mean ± standard error).

Street Type and Street Edge Side	Amount of Visual Engagement with Street Edges on Different Sides of a Street when Undertaking Different Activities (Entire Street Visual Engagement)			Amount of Visual Engagement with Street Edges on Different Sides of a Street along Different Streets (Entire Street Visual Engagement)	
	Optional Activity	Necessary Activity	LRT Result	Streets Walked (Range)	LRT Result
Walked side of non-pedestrianised street	37.9% ± 3.2%	17.7% ± 2.0%	36.61, $p < 0.001$	15.6% ± 2.6% to 40.5% ± 5.6%	34.05, $p < 0.001$
Opposite side of non-pedestrianised street	13.2% ± 1.5%	6.8% ± 0.9%	14.51, $p < 0.001$	6.0% ± 1.2% to 13.5% ± 2.8%	9.43, $p = 0.09$
Left side of pedestrianised street	26.0% ± 3.1%	13.8% ± 1.9%	15.44, $p < 0.001$	13.2% ± 2.8% to 28.8% ± 3.5%	20.18, $p < 0.001$
Right side of pedestrianised street	21.6% ± 2.6%	14.4% ± 1.8%	7.99, $p = 0.05$	7.8% ± 1.6% to 30.0% ± 2.8%	26.72, $p < 0.001$

The different non-pedestrianised streets walked influenced the amount of visual engagement with the street edge on the walked side, but not the street edge on the opposite side (see Figure 5C and Table 4). The different pedestrianised streets walked influenced the amount of visual engagement with both the street edges on the left and right sides (see Figure 5D and Table 4).

3.5. Research Question 3: Are there Differences in the Amount of Visual Engagement upon (i) Street Edge Ground Floors between Non-Pedestrianised and Pedestrianised Streets and (ii) Street Edge Sides between Non-Pedestrianised and Pedestrianised Streets?

To determine if the amount of visual engagement with street edge ground floors varied between non-pedestrianised and pedestrianised streets, Welch two-sample *t*-tests were performed. The amount of visual engagement with the street edge ground floors did not vary between the non-pedestrianised and pedestrianised streets (Table 5).

Table 5. The difference in visual engagement upon street edge ground floors and street edge sides between non-pedestrianised and pedestrianised streets (mean ± standard error).

Street Edge Area	Amount of Visual Engagement across Street Types (Only Street Edge Visual Engagement)			Amount of Visual Engagement across Street Types (Entire Street Visual Engagement)		
	Non-Pedestrianised Street	Pedestrianised Street	*t*-Test Result	Non-Pedestrianised Street	Pedestrianised Street	*t*-Test Result
Ground floor	90.1% ± 2.0%	91.7% ± 2.5%	t (108.24) = 0.72, $p = 0.48$	34.2% ± 2.4%,	34.8% ± 2.8%	t (122.86) = 0.17, $p = 0.86$
Difference in visual engagement between street edge sides	46.8% ± 3.7%	35.0% ± 3.6%	t (129.54) = 2.27, $p = 0.02$	18.7% ± 2.2%	12.4% ± 1.7%	t (126.45) = 2.27, $p = 0.03$

The difference in the amount of visual engagement upon street edges of the same street was calculated and Welch two-sample *t*-tests were performed to determine if these differences varied between non-pedestrianised and pedestrianised streets. The difference in street edge visual engagement between the sides of non-pedestrianised streets was greater than the sides of pedestrianised streets (Table 5).

4. Discussion

The current investigation provides detailed empirical insight into pedestrian visual engagement with different areas of urban street edges through the use of mobile eye-tracking. The study findings demonstrate, as predicted, that people visually engage with street edge ground floors more than

upper floors, that visual engagement is distributed more towards the street edge on the walked side of non-pedestrianised streets than the opposite side, and that visual engagement with street edges of pedestrianised streets is balanced across both sides. However, as also anticipated, differing everyday activities and streets walked significantly influenced the amount of visual engagement upon all these street edge areas, except the street edge on the opposite side of non-pedestrianised streets, which was not predicted.

The study insights advance understanding of street edge visual engagement in a manner that has previously been challenging to attain. This subsequently provides opportunity to evidence existing understandings and assess how street edge design intervention can align to a greater extent with the way in which street edges are engaged with by pedestrians. This is outlined in the following discussion.

4.1. The Focus of Visual Engagement upon Street Edge Ground Floors

The current study shows that pedestrians visually engaged more with street edge ground floors than upper floors along both non-pedestrianised and pedestrianised streets. This insight supports previous work describing the experiential significance of ground floors [19,20], especially the concepts of Gehl [1] and his *city at eye-level* and Glaser et al.'s [2] *street plinths*. It is also notable that the current study findings correspond well with Glaser et al.'s claim that ground floors determine 90% of peoples' experience of buildings that flank streets. The current study highlighted that 90%–92% of people's visual engagement takes place with the ground floor of street edges. However, ground floor engagement was shown to be less, at 34%–35%, when taking into account visual engagement with the entirety of the whole street.

Highlighting the focus of visual engagement upon ground floors supports the understanding that street edges should not be understood as singular entities with pedestrian experiential engagement distributed equally across their entirety. Instead, they need to be approached across multiple scales [2,36,37]. Within this, ground floors require consideration as a distinct scale embedded within the overall built morphology of street edges [2,34,38]. Significantly, this mind-set has implications for the way in which design intervention is approached, especially when seeking to create street edges that are more experientially engaging for pedestrians. Delineating ground floors as an experientially salient street edge scale provides better opportunity and scope for decision-making attention to be focused on their specific requirements [38,39]. Ground floors are therefore not solely regarded as the point at which buildings make contact with the ground and the dominant focus of interest is not just the aesthetic qualities and overall form of entire buildings [1,2,53], the totality of which pedestrians rarely visually engage with. Instead, ground floors become a point of decision-making focus in their own right based upon the knowledge that people overwhelmingly engage with them.

4.2. Visual Engagement with Street Edges on Different Sides of a Street

The study findings highlight that pedestrians walking along non-pedestrianised streets visually engaged with the street edge on the walked side significantly more than the opposite street edge. This insight evidences the notion that street edges of the same street should be considered as experientially separate, even though both contribute to the spatial totality of a street [1,34,37]. It also brings into question the understanding that streets are experientially a *place between the edges* [37]. Instead, non-pedestrianised streets required greater consideration as a place between two experientially distinct edges, with pedestrian engagement focused towards the walked side street edge. Such a mind-set has subsequent implications for street edge design decision-making. Currently, streets and their edges are often approached in their totality. This is especially important when seeking to influence factors such as pedestrian walkability and the overall liveability of urban environments [35,42,43]. Even though, within certain situations, it is appropriate to think of streets in this way, intervention within street edges should also be considered on a side-by-side basis. This is along with the need for design decision-makers to anticipate that pedestrians on different sides of a street will not visually engage with street edge interventions to an equal extent.

The study findings show that there was no significant difference between the amount of visual engagement across the street edges on different sides of pedestrianised streets. The significance of this is examined in the section that follows when reflecting upon the impact of pedestrianisation upon street edge visual engagement.

4.3. The Influence of Pedestrianisation upon Street Edge Visual Engagement

There was no difference highlighted between the dominant amount of visual engagement with street edge ground floors of non-pedestrianised and pedestrianised streets. This further evidences the need to consider street edge ground floors as experientially significant, regardless of street type [1,2,34]. As examined in the earlier ground floor discussion, such insight highlights the need to focus attention upon ground floors as experientially distinct from the overall built morphology within which they are embedded [2,38].

The current study findings show that visual engagement was more balanced across both street edges of pedestrianised streets than the street edges of non-pedestrianised streets. Previously, there has been limited systematic exploration of the way in which pedestrianisation influences peoples' engagement with the surrounding street environment, particularly its edges. The current investigation addresses this limitation, with the insights obtained offering subsequent opportunity to inform design decision-making. As shown, pedestrianised streets afford more open and less-restricted distribution of visual engagement. As a result, they provide a spatial setting that encourages visual engagement with a greater proportion of opportunities within the surrounding street edges. This is significant when considering the fact that pedestrians direct a predominant amount of their visual engagement towards street edges as they build an understanding of what the surrounding setting offers them [1,2,14]. When seeking to establish urban streets that are more engaging, it is therefore beneficial to consider the way in which pedestrianisation significantly influences the extent to which people visually engage with the totality of what the surrounding street edges offer them.

4.4. Everyday Activities and Differing Streets Walked Influence Street Edge Visual Engagement

Optional activities encouraged a greater amount of visual engagement, in comparison to necessary activities, with the street edge ground floors and street edges on different sides of both non-pedestrianised and pedestrianised streets. This insight adds further detail, from a direct pedestrian perspective, to the observations of Gehl [1] and corresponds with previous mobile eye-tracking research [14]. It also provides new insight into the way that pedestrians can be considered as active perceivers, through the way in which their everyday activities significantly influence and mediate their engagement with the surrounding environment [26]. The current study findings thus further the argument that people engage with urban environments in an enactive manner, with combined social influences and spatial factors influencing the urban experience [40,41].

The differing streets walked influenced the amount of visual engagement upon the street edge ground floors of non-pedestrianised and pedestrianised streets. They also influenced the amount of visual engagement with both the left and right sided street edges of pedestrianised streets and the street edges on the walked side of non-pedestrianised streets. Such insight advances systematic understanding of the extent to which varying streets influence visual engagement with different street edge areas. Future research, again using mobile eye-tracking, could build upon this foundation through a focused analysis of what specific physical and material attributes of the environment influence street edge visual engagement. This would provide empirical insight into what specific characteristics of the environment visually engage pedestrians, subsequently providing opportunity to inform design decision-making.

The current investigation captured no difference in the amount of visual engagement with the street edges on the opposite side of non-pedestrianised streets. This insight was not anticipated. It does, however, provide opportunity to consider how the spatial composition of these streets, along with objects within the street, restricted visual engagement to the walked side to such an extent that there

was no opportunity for significant variation in visual engagement with the opposite street edge. This provides further opportunity to evidence the potential experiential benefits of pedestrianisation, which afford more open visual engagement with the surrounding street edges, as shown during the current investigation. However, further systematic investigation is needed to examine such ideas in detail.

4.5. Study Limitations and Future Research

The current study provides a new empirical understanding of the way in which pedestrians visually engage with urban street edges. Even though this is the case, it is beneficial to acknowledge that there are a number of factors stemming from the current research that require further consideration. There is also opportunity to highlight future research opportunities.

The current investigation did not look at assessing how differences in the characteristics of the street edges examined, or the composition of the streets walked, might have influenced pedestrian visual engagement. Instead, the focus was on capturing general principles and clear patterns in the way that people visually engage with street edges. Beyond the fact that the study streets could be categorised as non-pedestrianised or pedestrianised, they clearly have distinct features and attributes that may have influenced where people looked in the street (see Figure 3). This highlights an opportunity for future research, which could more systematically examine the effect of specific street and street edge characteristics on street edge visual engagement.

We believe that findings from the current study are transferable to broader situations, with the findings obtained validating and building upon previous insight attained within differing urban contexts. It needs to be acknowledged, however, that data collection during the current study took place within a specific urban environment categorised by a certain type of European urbanism (see Figure 3). Further investigation would help to determine if the insights obtained during the current study can be seen when assessing visual engagement with street edges in other urban settings with contrasting types of urbanism. The current investigation also focused on the examination of pedestrian engagement with commercial city centre urban street edges. It would be interesting so see how visual engagement is distributed upon different street edge typologies, particularly residential street edges.

Mobile eye-tracking outdoors provides detailed insight into the way in which people visually engage with their surroundings at the same time as being immersed within the reality of real-world urban settings. However, when people are situated within such environments, it can be difficult to assess if their attention, along with second-by-second perceptual processing, is actually being directed towards what they are looking at within the often diverse and multi-sensory environment around them. This is due to their being heightened potential for them to be cognitively processing aspects of their wider surroundings or something they have previously engaged with (21). Future research could take this into consideration by attempting to link mobile eye-tracking with wider data collection methods, such as mobile electroencephalogram (EEG) (19,20). This has the potential to provide more robust insight through establishing a stronger link between gaze distribution and cognitive processing. However, the development of such an approach is still at a stage of infancy, with methodological issues needing to be overcome (20).

5. Conclusions

The social and experiential significance of urban street edges has long been understood. However, their potential to be engaging and stimulating for pedestrians has recently been impacted by issues such as high street decline and a reduction in the variety of functions they offer. These factors have triggered the need to gain greater insight into how contemporary street edges are experienced, building upon the broader consideration that there is currently a limited empirical understanding of the way in which street edges are experientially engaged with from the direct perspective of pedestrians. The current investigation addresses this limitation through the use of mobile eye-tracking along both pedestrianised and non-pedestrianised streets. The study findings demonstrate that people visually engage with street edge ground floors more than their upper floors along both non-pedestrianised

and pedestrianised streets; that visual engagement is distributed more towards the street edge on the walked side along non-pedestrianised streets; and this contrasts with visual engagement upon the street edges of pedestrianised streets, which was balanced across the edges on both sides. The current investigation also highlights how everyday activities of pedestrians and differing streets walked both have the potential to impact visual engagement with the street edge areas examined. As a result, the study advances our empirical understanding of pedestrian street edge experience. With this in mind, the current investigation subsequently examined how such insight could inform the way street edge design intervention is considered and approached. This was pursued in an attempt to highlight how street edge decision-making can align to a greater extent with the way that pedestrians visually engage with these realms. Such alignment is essential in order to ensure that street edges remain socially and experientially engaging aspects of urban environments that can contribute to peoples' day-to-day quality of life long into the future.

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