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Assessing the Impact of a New Urban Greenway Using Mobile, Wearable Technology-Elicited Walk- and Bike-Along Interviews

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Abstract: Physical inactivity is the fourth leading risk factor for global mortality, causing an estimated 3.3 million deaths worldwide. Characteristics of the built environment, including buildings, public spaces, pedestrian and cycling infrastructure, transportation networks, parks, trails and green spaces can facilitate or constrain physical activity. However, objective study of built environment interventions on physical activity remains challenging due to methodological limitations and research gaps. Existing methods such as direct observations or surveys are time and labour intensive, and only provide a static, cross-sectional view of physical activity at a specific point in time. The aim of this study was to develop a novel method for objectively and inexpensively assessing how built environment changes may influence physical activity. We used a novel, unobtrusive method to capture real-time, in situ data from a convenience sample of 25 adults along a newly constructed urban greenway in an area of high deprivation in Belfast, UK. Walk/bike-along interviews were conducted with participants using a body-worn or bicycle-mounted portable digital video camera (GoPro HERO 3+ camera) to record their self-determined journeys along the greenway. This is the first study to demonstrate the feasibility of using wearable sensors to capture participants' responses to the built environment in real-time during their walking and cycling journeys. These findings contribute to our understanding of the impact of real-world environmental interventions on physical activity and the importance of precise, accurate and objective measurements of environments where the activity occurs.

Keywords: wearable sensors; physical activity; walk-along; bike-along; transportation; recreation; neighbourhoods

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1. Introduction

Rising levels of physical inactivity have been a cause for concern globally [1]. Physical inactivity is the fourth leading risk factor for global mortality, causing an estimated 3.3 million deaths worldwide [2,3]. In the UK, physical inactivity is responsible for one in six deaths (equal to smoking) [4]. It is estimated to cost the government GBP 7.4 billion annually, including a direct expenditure of one billion incurred by the National Health Service [5]. Around 1 in 3 (34%) men and 1 in 2 (42%) women are inactive, and people with disabilities or long-term conditions are twice as likely not to be active enough for good health [5,6]. The UK population is around 20% less active than in the 1960s, and if current trends continue, it will be 35% less active by 2030 [3].

The coronavirus disease-2019 (COVID-19) pandemic has altered the way people can be active, because many jurisdictions closed or limited access to common indoor and outdoor places for physical activity (PA) [7]. Across the globe, people were advised to stay at home and avoid contact with individuals outside their households. Lockdowns and physical

distancing measures restricted access to gyms, parks, playgrounds and other avenues where people could be physically active [8].

Regular PA can prevent and manage several common pre-existing chronic conditions including obesity, heart disease, type 2 diabetes, and some cancers, which also increase the risk of severe COVID-19 infections and mortality [9,10]. Promoting active living (i.e., a way of life that integrates physical activity into everyday routines, such as walking to the store or cycling to work) is a feasible and cost-effective way to incorporate regular PA into daily life [11]. Walking and cycling are recommended forms of moderate-to-vigorous PA that can serve as modes of travel to substitute for short car trips [12].

Extensive research evidence suggests that the built environment (BE) can facilitate or constrain PA [13,14]. BE's that are PA-friendly depend upon an appropriate integration of land use and transportation infrastructure, density, pedestrian infrastructure such as footpaths, crosswalks, bicycle lanes, and public transit [10,15]. Numerous studies have demonstrated that individuals living in higher walkability neighbourhoods (characterised by high residential density, mixed land use, transit accessibility and street connectivity) tend to walk or bike more than those living in automobile-dependent neighbourhoods [10]. In addition, parks, playgrounds, and other green spaces promote mental health and well-being by reducing stress, stimulating cognitive function, enhancing social cohesion, and supporting PA [16]. A recent review of longitudinal studies found that residents living in walkable neighbourhoods are less likely to develop obesity, type 2 diabetes, and hypertension over time than those living in less walkable neighbourhoods [17].

To date, studies seeking to quantify how features or changes in the BE impact PA have employed extensive in-the-field observation, surveys, or census data [18]. These methods provide a limited cross-sectional view of PA behaviour at a specific point in time [18]. However, research has suggested that continuous, objective and long-term evaluation of BEs is crucial for implementing PA programmes and interventions [19]. The use of direct observation tools in the field (e.g., System for Observing Physical Activity and Recreation in Communities (SOPARC)) have overcome some constraints in their ability to provide objective, context-rich information on PA [20,21]. However, these data are static since areas being observed (e.g., parks, recreation areas) are divided into predetermined target areas and studied by trained observers. Other limitations of direct observation instruments are the time-intensive nature and costs involved in data collection [21].

Features of the BE influence PA, but there are numerous gaps for an objective study of the effects of the BE on PA [22]. A challenge in evaluating the influence of the BE on PA is to eliminate researcher and respondent bias [23]. Several obstacles remain to undertaking longitudinal observations of Bes over larger spatial and temporal settings in an efficient and cost-effective manner. New developments in wearable sensors and mobile technologies offer opportunities to obtain geospatial data about Bes and PA behaviours that may circumvent the limitations of traditional data sources [24]. Commercial wearable products to monitor PA and mobility that can be worn on a specific part of the body (e.g., pedometers, accelerometers) have become popular and easily accessible to general users due to their portability and relatively low-cost [25]. These sensors enable long-term monitoring of PA and human behaviour in a free-living environment [26,27]. Advantages include real-time, in situ surveillance and the ability to record the specific nature of daily activities and locations where a user engages in them. However, they do not capture information on the context in which the study is being performed.

The aim of this study was to develop a novel method for objectively and inexpensively assessing how BE changes may influence PA. We hypothesised that the use of wearable sensors would improve on existing methods to capture participants' responses to the built environment in real-time during their walking and cycling journeys. In this study, we used data captured from wearable sensors to objectively assess the impact of a new urban greenway intervention on PA in the most deprived neighbourhoods in Belfast, UK. Participants' real-time mobility responses to the built environment were assessed using

walk-along and bike-along interviews to elicit in situ responses during journeys along the greenway.

2. Methods

2.1. Study Context

The Connswater Community Greenway (CCG, http://www.communitygreenway.co.uk/ accessed on 29 October 2018) is a large scale, inner-city urban regeneration project in East Belfast, Northern Ireland, UK (Figure 1) [28]. The study area for this project was defined as 22 electoral wards in the political constituency of the CCG, with a total population of approximately 87,500 residents. East Belfast is an area of high deprivation, and seven of these wards are ranked within the top 25% most deprived wards with disproportionately poor health, low skills, low educational attainment and a poor living environment as measured by Northern Ireland's indices of deprivation [29]. Funded primarily by a Big Lottery Living Landmarks Award, the local city council and government departments, CCG is a GBP 32 million investment which aims to regenerate the local environment and physically reconnect communities to improve the health and well-being of residents.

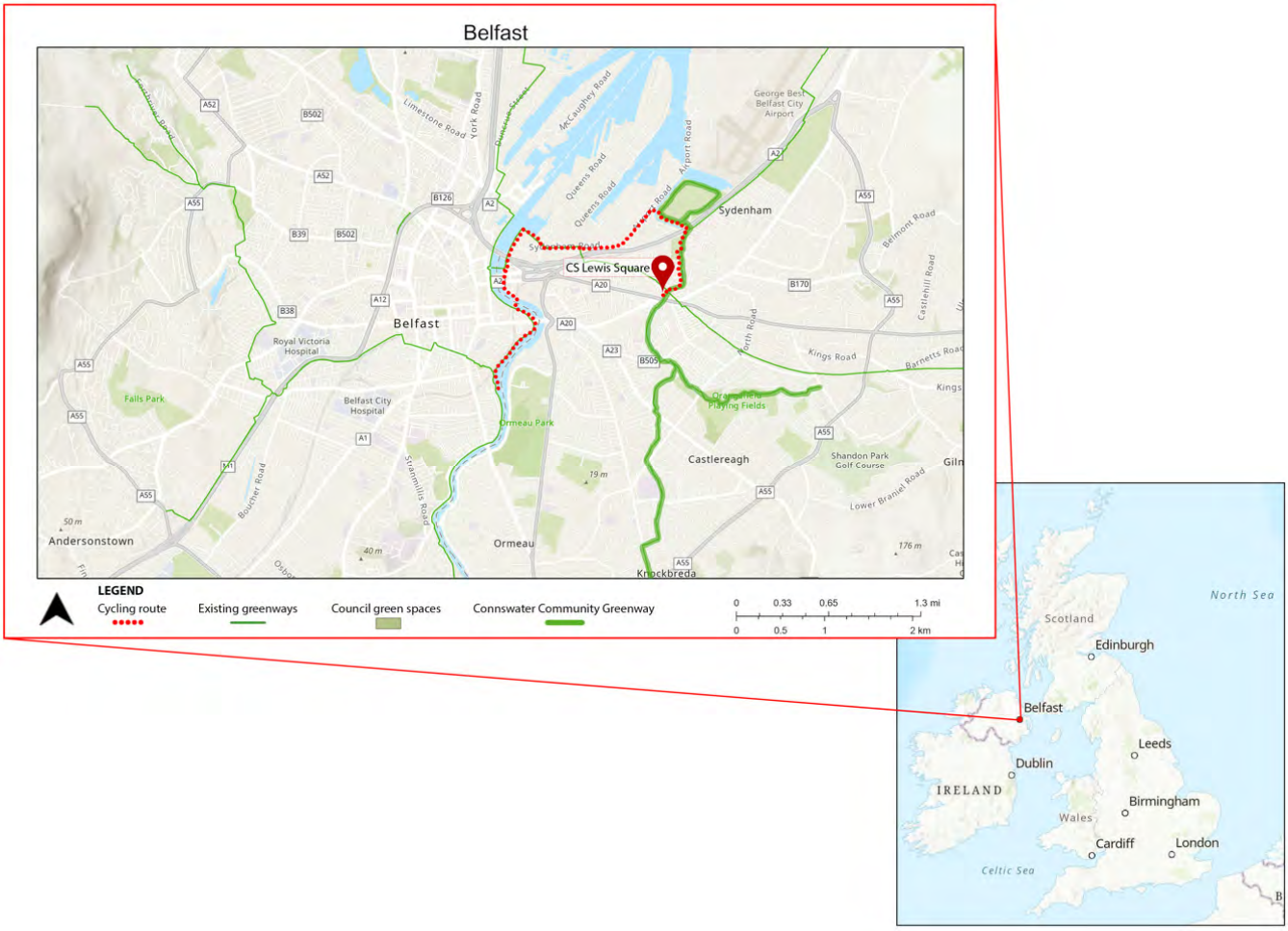

Figure 1. Location of the Connswater Community Greenway, Belfast, Northern Ireland, UK.

Specific aspects of the regeneration include: the creation of a 9 km urban greenway along the course of three rivers (Connswater, Knock and Loop rivers), 16 km of new or improved foot and bicycle paths, 5 km of remediated water courses, development of a new civic square, development of 8 tourism and heritage trails, 23 new or improved bridges or crossings, 22 new signage points, installation of public art and sculptures, 13 hectares of upgraded parks, 2 multiuse outdoor play areas and 2 new toilets. A wildlife corridor

was created following extensive landscaping and biodiversity enhancement efforts. Due to decades of underinvestment in the area, the open spaces alongside the rivers were previously underused, inaccessible, unsafe and disconnected from the communities. The CCG has created a safe and welcoming public space for residents and visitors to East Belfast.

2.2. Data Collection

This urban regeneration project provided an opportunity to assess the impact of the CCG on PA using novel technologies such as wearable sensors and video footage. Walk-along and bike-along interviews using body-worn video cameras were conducted with residents to elicit responses during a journey along the CCG. These novel methods provided a real-time, in situ method of recording participants' experiences along the CCG.

Between June 2019 and July 2020, participants (n = 25) were recruited using a convenience sampling approach. Information about the study was distributed through flyers, social media and the CCG mailing list, requesting interested individuals to contact the research team for more information. A description of the project was provided to interested and eligible participants. Eligibility criteria for participants included: (i) aged 18 years or above; (ii) able to converse in English; (iii) able to walk or bike independently for 30–45 min; and (iv) no signs of cognitive impairment. An appointment to meet the researcher in a designated location along the CCG was made with individuals who agreed to participate. Participants provided written consent and agreed to participate in the walk-along or bike-along. Study procedures were approved by the Research Ethics Committee at Queen's University Belfast, UK (reference number EPS 19_180, June 2019).

Each interview consisted of two stages, both of which were audio recorded. During the first stage of the interview, participants were asked questions that assessed demographic characteristics, frequency of visits to local public spaces in a usual week, duration of visits, and types of physical activities normally performed in those spaces. In the second stage, the participant and interviewer undertook a semistructured walk-along (n = 12) or bike-along (n = 13) interview along the CCG. During the walk-along or bike-along, the participant used a body-worn or bicycle-mounted portable digital video camera (GoPro HERO 3+ camera) to record the journey (Figure 2). This camera provided a high-quality, three-dimensional video of participants' journeys. The camera was only pointed at the surrounding area and was not used to record the participants' facial expressions or reactions.

After the walk or bike ride, the recorded video was replayed to the participants. Participants were encouraged to pause and rewind through the video as they spoke freely about their journeys. A semistructured interview was conducted with each participant, using an interview guide developed for this study consisting of open-ended questions that encouraged participants to speak freely about what they felt was relevant and important in terms of their journey along the CCG. The interviewee adopted a conversational style. As the video was replayed to participants, the interview guide was used to navigate the conversation, with questions on perceptions of the built environment, quality of the greenway, neighbourhood parks and playgrounds, travel behaviours, choice of route, and social interactions with the community. We believe this facilitates more authentic descriptions of the experience, less prone to recall bias. Interviews were conducted during daylight hours and under good weather conditions, with each interview lasting between 55 and 75 min (mean = 62 min). The routes (mean = 1.5 km) were determined by the participants and took place in plain sight along the main walking or cycling paths of the CCG, avoiding hidden or sheltered areas (e.g., densely planted paths, forest areas).

This qualitative study employed a grounded theory approach to guide the sample size [30,31]. Theoretical saturation of data was used as a parameter to determine the number of participants required for a detailed analysis [32]. There are no fixed sample sizes or standardised tests to estimate the amount of data needed for achieving saturation. In this study, theoretical saturation was achieved where no new information, concepts or themes were emerging from the data. Key themes on the role of the environment for physical activity emerged through the process of inductive analysis [33]. The research team

developed a hierarchical, nested coding schema. Data were analysed and categorised into key themes by common grouping patterns that emerged from the interviews. Interview transcripts were analysed and independently coded by two members of the research team for consistency and rigour. The coding structure and themes were validated in consultation with an external advisory group to ensure the validity of themes emerging from the data. This process was used to resolve disagreements in coding and reach a consensus.

Figure 2. Bicycle-mounted Go-Pro camera on the mounting base that rotates 360° to give different camera angles.

3. Results

Study participants ranged in age between 22 and 75 years (median age = 46 years), of which half (50.5%) were female. Participants discussed the benefits of urban green spaces, park quality and barriers to walking and cycling. Experiences of the CCG varied among regular users compared to new visitors who were unfamiliar with the area. Although the journeys were unique to participants, there were many similarities in the participants' perceptions of built environment features. Some constraints were unique to individuals, but a majority were shared by participants. Notably, safety was perceived differently among the

participants. Key themes (Figure 3) that emerged from the data have been categorised as follows: (1) physical factors; (2) social factors; (3) policy factors; and (4) individual factors.

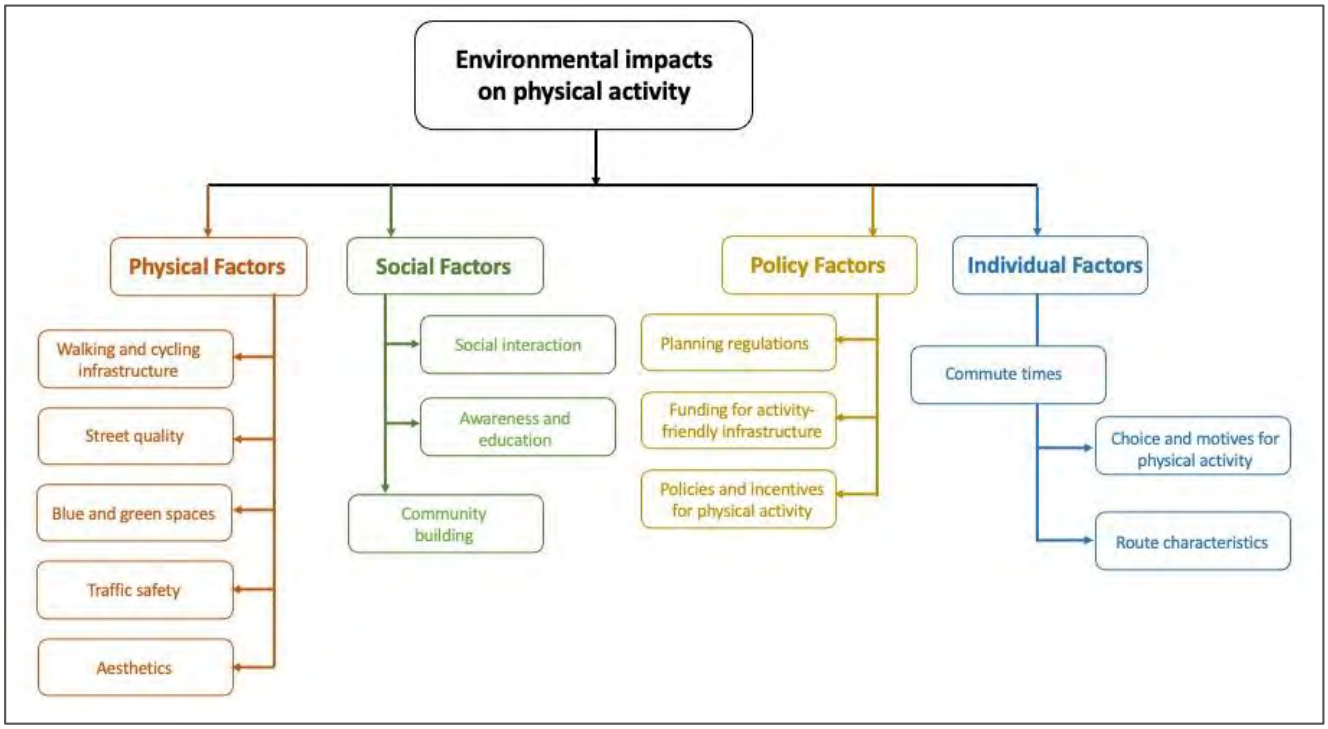

Figure 3. Schematic diagram illustrating key themes and subthemes on environmental influences on physical activity that emerged from interviews.

3.1. Physical Factors

The walkways and bicycle paths were the most commonly used areas for PA. Participants with younger children preferred play parks and green spaces that were easily accessible and near their homes. The design and layout of the cycling and walking infrastructure and microscale street features were discussed. Participants emphasised the supportive features that made it possible for pedestrians and cyclists to coexist in the same space. At the microscale, good lighting in the evening and at night and availability of wide, even surfaces and pathways were important issues for cyclists:

> *"It's a lovely space, big wide path around it now, which can comfortably accommodate cyclists and pedestrians, so feels very safe." (Male, age 65)*

> *"That bit we just looked at the video that would be more what I would come here for leisure on a Sunday with a family or every Saturday come down, would come down this way to go to the park. It's not the quickest way but we do it because it's scenic." (Female, age 31)*

> *"I like this bridge especially at night and because it's well lit up, so this is real kind of attraction and a safety feature. You don't feel like you're going to hit a pedestrian." (Female, age 28)*

Though they may not have been active in them, participants appreciated pleasing views of the blue and green spaces along the CCG (Figure 4). The rejuvenated parks, rivers and woodland areas offered the simple pleasure of experiencing trees, birds, squirrels, and other wildlife in an urban environment. Participants discussed the importance of connecting to nature for emotional, psychological and physical health.

Figure 4. Images captured by GoPro cameras showing rejuvenated blue and green spaces along the Connswater Community Greenway.

> *"After along day at work, the greenery here offers a break and helps calm me down. It is like a soothing balm for the daily stress and busy lives. Going out for a walk or run uplifts my mood immediately." (Female, age 38)*
>
> *"Wonderful again, because you're seeing the city, you're seeing the water, you're seeing the reflections, and if you look to your right, you're seeing all the boats. So really pleasant, feels spacious with the Odyssey building [a sports and entertainment complex] on your left. It's a nice, pleasant approach to the city centre and the new bridge." (Male, age 52)*
>
> *"It really does feel like you're almost in the countryside here. Sitting here on a bench and breathing in fresh air, smelling the flowers, and just watching the ducks in the lake and different birds in the trees helps me connect with nature and makes me happy." (Female, age 66)*
>
> *"I did notice that it was going along, so you do hear some birds, bird song and things which is really nice, does give you the feel that you're actually, you know in the countryside in a nice rural setting." (Male, age 71)*

Some participants highlighted the role of nature as a motivating factor to visit the greenway often and engage in physical activity:

> *"I think it's quite nice. And then there is lake here, and I saw some swans there, it is very lovely to see some wild animals in parks. And you can see the kids play with the birds . . . it's very nice park and in summertime I know this park is really beautiful. You can see the swans and pigeons. It's not very frequent to see these animals in parks in Belfast. So maybe that would be a motivation for me to visit this park again." (Female, age 48)*

Risks from traffic and perceived safety were key concerns among several residents. Lack of safe walking and cycling infrastructure (e.g., safe footpaths, crossings) and street lighting were commonly reported barriers to physical activity. Cyclists experienced difficulty in safely navigating a narrow poorly lit section that goes through a single-lane tunnel

shared by cyclists, walkers and cars, and expressed concerns about visibility and street lighting (Figure 5):

Figure 5. Images captured by GoPro cameras highlighting narrow, poorly lit defunct paths and abandoned tunnels that are barriers for cyclists.

> *"An issue I have with this part coming into the tunnel is that you really risk getting hit by a car because as the tunnel is really long and very dark you can't see out." (Male, age 33)*

> *"The tunnel is a bit awkward. It's hard to see who's coming through the tunnel. On the way out, it's evident cars coming down and there's also some pedestrians in the tunnel so trying to manoeuvre around a car and pedestrians in the tunnel." (Female, age 41)*

> *"Challenge is really going into Victoria Park because you've got a tunnel, so you do have to be careful particularly if you are with group, you have to look out for the traffic, the visibility going into the park is a bit of a blind corner, dark in the tunnel, and it is not lit." (Male, age 44)*

In contrast to sections with wide footpaths, fear of collisions between pedestrians and cyclists was a concern in areas where bicycle lanes and footpaths were not well-defined or segregated and the width of the footpath was narrower. Selecting a safe gap in which to cross in front of oncoming traffic was a challenge for cyclists at some street intersections:

> *"This is particularly a bad area now, from a cyclist point of view, because that not really thought out how best to cross here, now there's a new road going in, and we hope that they'll improve this crossing. This is again a safe wide footpath. You just need to be mindful that there's traffic about, and traffic cutting in here. So, good sign to let you know you're on a route for pedestrians and cyclists." (Male, age 52)*

Attitudes of car drivers towards cyclists and pedestrians were perceived as a threat. Participants expressed the need to educate different users of greenway including cyclists and dog walkers. Some participants were discouraged by the lack of awareness of drivers within an industrial estate adjacent to the greenway:

> *"They don't tend to think that people are using that walkway. Because it's an industrial estate there is an assumption that it's cars and stuff so there's not a lot of foot passenger and so there's sometimes issues with them blocking the paving." (Female, age 46)*

> *"Try to educate people and make them think a bit more about their use of the greenway, whether it's cyclists who go too fast, and people with dogs either who should be on leads, or dogs that are on big, long leads, and people who just stop suddenly in the middle of the greenway." (Female, age 53)*

3.2. Social Factors

Participants described the greenway as a catalyst for meeting new people and improved social interaction. The greenway was perceived as a place that attracted new people and enriched the local community. While personal goals or desires were achieved, community building and increased social capital also emerged. Individual and community benefits, improved health, and social resilience were reported as key outcomes:

> *"In terms of the greenway, and this infrastructure that currently is in place, it is kind of a factor enabling people to talk to people who they don't know, talking to strangers that maybe you wouldn't normally do . . . I think it's hugely important. I mean along the greenway or in the park or C.S. Lewis square you meet people from different areas. On your street you meet your neighbours who are all maybe the same social status as yourself, but down here middle-class people can meet working-class, kids can meet adults. It's a big benefit, I think, of having a greenway." (Female, age 41)*

> *"However, I think particularly for people you know living in maybe you know built up areas or areas where they don't necessarily have a garden, having something like this on your doorstep as really a fabulous open space for people." (Female, age 45)*

Participants appreciated the social and cultural events organised by the CCG leadership team. These events provided opportunities for social interaction and helped residents develop social bonds:

> *"I was thinking about there's an event here on Saturday. That's the 24 h non-stop run. So, some people will run the equivalent of five marathons without stopping. They go all night, so I was starting to think a wee bit about that because we'll come down and watch that for a bit." (Male, age 62)*

> *"Again, got little bins good, well maintained area, there's a new shelter which is really good, and I noticed for events, so that's good to see, a thing that's just opened recently. And there's a play park here for children, so I always feel safe when I'm cycling around here." (Female, age 46)*

Participants reported increased communication and nonfamilial interactions between residents, improving social capital in the area. The newly developed green infrastructure and rejuvenated public spaces provided opportunities for residents to enjoy the outdoors at their doorsteps and meet their neighbours in a safe and pleasant environment. Successful nonfamilial interactions were achieved through shared experiences and meaningful outdoor activities along the CCG:

> *"It's hugely important I mean along the Greenway or in the park or C.S. Lewis square you meet people from different areas. I mean you know, on your street you meet your neighbours who are all maybe the same social status as yourself." (Male, age 71)*

> *"In terms of the greenway, and this infrastructure that currently is in place. Is it kind of a factor enabling people to talk to people who they don't know. You know talking to strangers that maybe you wouldn't normally do." (Male, age 62)*

3.3. Policy Factors

Participants were critical of local civic authorities for prioritising parking and motorised traffic in planning regulations, while neglecting the needs of other vulnerable road users. Threats from motorised traffic, and lack of priority given to pedestrians and bicyclists in local planning policy, emerged as key issues:

> *"We have repeatedly submitted appeals to the city council to create a linked bicycle network, but no one has acknowledged our requests." (Male, age 52)*

> *"We need to create more greenways across the city and the island at large. However, sadly, policymakers are focused on providing more parking spaces and encouraging car dependency. The greenway should be a role model for other councils and help them realise*

that green infrastructure has many benefits for health, physical and mental." (Male, age 44)

"I cycle to work every day. The greenway is excellent and safe, but the stretches where I have to cycle on the road are very risky. I am a member of a local bicycling community group and we have presented these issues to the authorities, but it is obvious that motorised traffic takes greater priority." (Female, age 28)

There was also strong support for the use of government funds to build activity-friendly infrastructure, redesign land-use requirements that would include walking and cycling paths and introduce initiatives to encourage people to engage in PA:

"It will be useful to use government funding sources to pay for protected bike lanes, rather than expanding road widths for vehicles." (Male, age 38)

"There is so much emphasis on infrastructure for cars, but very little revenue for pedestrians and cyclists. We are all equal road users, but the city's policies do not reflect that." (Male, age 52)

"We should have more car-free days and targeted initiatives that make it easier and safer for for people of all ages and abilities to ride." (Female, age 31)

Some participants encouraged employers to introduce policies and incentives to physical activity during the workday:

"Workplaces must encourage employees to cycle to work which can result in a healthier, more productive workforce. It is well-known that cyclists tend to take fewer days off sick and save the company money." (Male, age 42)

"Cycling is so much faster than driving, especially over short distances and when the roads are busy. It's easier for me to bypass traffic jams and I don't need much space at all to park once I arrive at work. I wish employers had office bikes or 'pool' bikes that would encourage more people to bike." (Female, age 46)

3.4. Individual Factors

Factors such as choice, motivation, affordability, personal safety, commute times, destination distance, route convenience, weather and the time of day played an important role in participants' PA. For the purposes of active travel, participants engaged in walking and cycling along the most direct route for work journeys, therefore convenience of the route was a greater priority than aesthetics:

"It's basically a route to get you from A to B. It's not for the visual experience or the environmental experience. It's simply a functional cycling route, which I would use if it's wet cold one day. You know, it's the most direct route." (Male, age 42)

"So, it's really handy that if I'm coming home, and I'm like oh I need milk, I know there's a shop where I will have secure bike parking and it's easy access and I can do it and obviously it gets more difficult when I have a bigger shop because I don't have like a car." (Male, age 38)

Choice and motives for cycling trips depended on weather conditions and the time of the day. Differences were observed between participants who were experienced cyclists and used the bicycle for daily commutes to work, in comparison with others who only walked or biked for recreation and leisure purposes.

"The weather can be a factor, but it only becomes more of a deciding factor when it's snowing or there is ice because the greenways aren't salted." (Male, age 71)

"I don't mind the rain because I've normally got my wet gear, but if it's windy at the same time as rain, that's tough. So yeah, probably just really bad weather." (Female, age 53)

"I don't cycle for commuting reasons, so it's probably only for leisure time, so if it is raining, it is not going to be enjoyable, so I would say I'm not going to cycle when the weather is not good here." (Female, age 38)

Participants discussed the financial benefits and cost-effectiveness of active travel. Walking and cycling was the cheapest, safest and most feasible way to travel for many participants:

> *"We do not own a car, so having this route so close to where we live is very convenient. It helps me and my partner cycle to work every day, and the cost savings for us are significant." (Male, age 42)*

> *"Walking or cycling is easy on the pocket. My bicycle was cheap to get, it is almost free to maintain, and it helps me get anywhere I need to be in the city." (Male, age 37)*

> *"We cannot afford to buy a new car now, so the greenway gave us a new lifeline. I was able to buy bicycles for myself and my kids. We all cycle together for the school runs in the morning and afternoon. It is actually very enjoyable, and my kids look forward to the rides." (Female, Age 38)*

Participants who biked to work in areas without defined or segregated bicycle lanes expressed safety concerns and tended to avoid peak traffic hours.

> *"I only cycle in the parks because there is no traffic. I am afraid of being knocked over by traffic when I am cycling on the road, so I avoid it." (Male, age 42)*

> *"It is risky. In the mornings especially, cycling on the road in all the traffic feels very dangerous. There are some intersections which are very dangerous and drivers do not give cyclists any space to navigate." (Female, age 28)*

> *"I would use it throughout the day, but I tend to actually plan my cycling around times that isn't peak traffic. I tend to not cycle during the busiest times of the day, so during rush hour, so normally, I think at the stage after six in the evening, so it's kind of a lot quieter." (Female, age 38)*

> *"I like that it's not on a road. It's direct. You know it's a strip route from the square to the park. Cuts a lot of traffic. Cuts a lot of public highways." (Male, age 38)*

Several participants reported improved physical and mental health. In addition, some shared that the segregated, safe greenway paths were supporting their recovery and contributing to better mental health:

> *"Some days that you are just not feeling the best, low mood, go out cycling and it lifts you; you forget about yourself. That's a good thing. Nothing is as bad as just sitting in the house. I got into cycling, you know I had an aversion to the Newtownards Road, and I wanted to hide from people, and my health has improved, my mental health has improved significantly." (Female, age 48)*

> *"One reason why I just love this here. It's safe. Because I had a bad accident, and I got knocked off my bicycle about two and a half years, ended up in the hospital, so and I still haven't recovered mentally to cycle on roads, I just don't like roads, don't like roads." (Female, age 46)*

4. Discussion

4.1. Summary of Findings

We demonstrate a novel method to objectively assess the impact of a new urban greenway intervention on PA using data captured from wearable sensors in a deprived region of Belfast, UK. Our findings complement existing quantitative evidence and provide a novel framework to capture information on PA behaviours and environments for future studies. Socioecological models posit that health behaviours such as PA have multiple interacting levels of influence, including individual, physical, social and policy factors [34,35]. Therefore, techniques that capture this wide range of factors can best explain PA behaviour. We demonstrate the feasibility of wearable sensors to capture the multifactor impact of an environmental intervention, and how this information can lead to a deeper understanding of what must change to create healthy, equitable and sustainable cities. Real-time, in situ

monitoring of participants provides a deeper understanding of the multiple pathways through which the environment impacts PA and commute mode decision-making. Our findings add to the evidence on walkable, activity-friendly neighbourhoods, and highlights specific functional, aesthetic, destination and safety features in the microscale environment that affect the way people travel, commute, exercise and play outdoors [10,36].

4.2. Relevance of the Findings to the COVID-19 Pandemic

The findings from this study are timely and relevant, as the COVID-19 pandemic has exacerbated socioeconomic inequities in PA [36]. Many people, especially those with low incomes, do not have equipment, internet access, or indoor space to make at-home PA a viable option [37]. Low-income communities faced compounding disparities in accessing basic needs during the pandemic due to their curtailed mobility, limited or no access to public transport, and greater vulnerability to infection [38]. Harnessing the power of emerging technologies such as wearables can be used to identify changes in patterns of PA, pedestrian and cyclist movement, and crowding hotspots during the pandemic [39].

4.3. Implications in Terms of Individual-Level Influences on Physical Activity

The way individuals perceive their environment influences physical activity levels and the use of urban greenspace. For example, in a study of women in socially disadvantaged communities, perceived safety mediated relationships between PA and social environment determinants [40]. These types of factors are usually measured using questionnaires. Wearable technology offers a new opportunity to capture these factors and specifically the microenvironment features that influence them.

Safe and convenient options for walking and bicycling are of profound importance for low-income communities facing transport inequities. Many low-income families cannot afford a car and live in neighbourhoods where public transportation options may be limited or not available at all [41]. In these circumstances, accessing basic needs is time-consuming, dangerous, and sometimes almost impossible. Walkable, activity-friendly neighbourhoods enable people at all income levels to travel to work, to school, and for daily needs using safe, healthy transport modes [36].

Personality traits, choices and motivation have been linked to PA engagement and the type of PA one chooses to engage in [42]. Specific participatory motives (e.g., enjoyment) are hypothesized to lead to greater engagement in PA (e.g., frequency, adherence). The weather has been suggested as an environmental factor affecting PA, but studies have shown that people who find PA most enjoyable were least likely to cite the weather as a barrier [43].

It is important to note that the factors identified in this study may interact with other factors at both "higher" levels of broad social policy and "lower" levels that operate at the individual level [44]. For example, environments that discourage PA may also limit social interactions, with potential implications for antisocial behaviour, violence, crime and drug use [45]. The absence of public transportation may interact with personal sources of stress (e.g., from home or work) and significantly impact unemployment rates in areas where people depend on it to reach their desired destinations [46].

4.4. Implications in Terms of Social Environment Influences on Physical Activity

Strong social connections are linked to lower rates of early mortality, less fear of crime, reduced loneliness, and better physical health in vulnerable populations [47]. Targeted promotion of the greenway in distinct population segments (e.g., children and youth, young mothers, unemployed, older adults, disabled populations), school-based PA initiatives, neighbourhood walking groups, and various community-based social marketing initiatives have encouraged the use and uptake of the CCG. This dual approach combining changes to the physical environment simultaneously with promotional events and programming was an important intervention component. Overall, participants have reported that the

CCG interventions have increased access to parks and green space, enhanced community cohesion and boosted local economic growth.

Previous studies have established that neighbourhood open spaces and parks are linked to improved health outcomes, PA, a sense of community and reduced stress levels [10]. Neighbourhoods with higher levels of green infrastructure foster social cohesion and reduce feelings of loneliness, which are key predictors of health [48,49]. While the impact of the built environment on PA has been established, the role of the social environment is less clear, despite its equal and potentially more prominent role in shaping PA [50]. Our study identified important influences of the built and social environment on physical and mental health in an area of high deprivation where access to nature was previously limited. Our findings highlighted the critical role of nature—green spaces such as parks, woodland and forests as well as blue spaces such as rivers and wetlands—in supporting good physical and mental health, promoting social connections and alleviating stress.

4.5. Implications in Terms of Physical Environment Influences on Physical Activity

The CCG is a large-scale, complex urban intervention comprising multiple components with the potential, individually and interactively, to affect the behaviour of a diverse population in a disadvantaged area in Belfast [28]. Our methods identified microscale factors in the physical and social environment that may influence PA but have not been studied as extensively as macrolevel factors. Microscale design elements in the built environment differ from macrolevel design elements such as street connectivity, land-use mix, and residential density, and include details about footpaths, streets, intersections, and design characteristics (e.g., road crossing features, aesthetics, lighting, presence of trees, bicycle lanes, curbs), as well as characteristics of the social environment (e.g., presence of garbage/litter/waste, graffiti, vacant lots in poor condition, abandoned buildings or cars) [51]. Studying microscale factors allows for a more fine-grained examination of the environmental features that enable or inhibit PA and may be modified more easily, cost-effectively and in less time than macroscale characteristics [52].

4.6. Strengths and Limitations

We identified various individual, social, physical and policy environmental factors affecting PA behaviours that can help in the development of more tailored intervention strategies for promoting higher PA levels. In comparison with surveys, direct observation methods, retrospective reports and daily diaries, data from wearable sensors can capture real-time mobility responses to the environment and are not subject to recall or other sources of bias. The unobtrusive and objective nature of data from video footage and their ease of use is an important strength of this study. The technologies we have used provide a cheaper and efficient alternative for the precise tracking of PA across large spatial and temporal settings.

Modern wearables and associated technologies that provide real-time monitoring and feedback can encourage healthy behaviours and empower individuals to better manage their health [53]. The technologies used in this study are noteworthy because they can: (i) continuously monitor and evaluate PA and BEs across wide geographical areas; (ii) improve the ongoing, systematic collection and analysis of BEs for public health evaluation due to real-time capabilities; (iii) significantly increase the ability to investigate PA patterns in situ; (iv) significantly increase external validity of measures and findings through ease of use, transferability, and wider applicability; and (v) address the need for research on cyberinfrastructure required to cope with big data (multiple streams, aggregation, visualisation, etc.) [54]. Wearable devices can also characterize health-related behaviours and assist with a variety of behaviour-change interventions that aim to promote PA such as walking and cycling [55]. This is particularly relevant given that even small changes in behaviour could have far-reaching consequences for population health [56]. Wearable technology is a rapidly expanding healthcare market, with several large technology companies including Apple, Google, Fitbit, and Garmin developing digitally enabled tools,

machine-learning algorithms, and tracking devices to monitor health. PA trackers that count steps, distance, intensity, and calories, can help users maintain health and fitness goals. Combined with other monitoring systems such as heart monitors, electrocardiogram applications, temperature and reproductive cycle trackers, wearables are becoming more prominent in the day-to-day management of illnesses and chronic conditions.

Walk-along and bike-along interviews have more methodological advantages than the traditional style of sit-down interviews. In this study, they provided a hybrid interviewing style, where a flexible interview schedule was tailored to the participant and adapted to their responses. Unlike sit-down interviews where the participants' description of their experience is based on memory recall that may be biased or inaccurate due to social-desirability or recall biases, a walk-along or bike-along interview captures participants' responses to environmental stimuli in real-time. This ensured that their observations, responses, and statements are directly attributed to the environment they relate to. This is significant for PA promotion because more precise measurement allows investigators to better understand where, when, and how activity occurs and the characteristics of the environments where it occurs, thus enabling more effective design and planning of public spaces, parks, streets, neighbourhoods and cities.

A key benefit of walk-along and bike-along interviews is that they are conducted in situ, which facilitates rapport between the interviewer and interviewee. Being interviewed in a familiar environment helps alleviate some of the pressure an interviewee may perceive in a formal sit-down interview. When the interviewees are comfortable within the setting, they are more likely to be more open and answer questions with honesty, allowing the interviewers to be more accurate in their responses and interactions to the shared comments and thoughts [57]. Thus, the interviewer and interviewee can have a more dynamic conversation, allowing the surrounding environment to shape their questions and responses, helping to avoid awkward lulls throughout their dialogue by simply pointing out an environmental feature and asking the participant for their perspectives.

Despite the above advantages, wearable technologies have certain limitations in providing complete information on PA and active mobility [58]. Access to wearable sensors and devices differs across user groups, and in some cases, the information input is entirely reliant on the individual's willingness to engage with and accept the technologies [59]. The use of wearable sensors raises several legal, ethical, and cultural issues associated with collecting, storing, and analysing these data. Issues include informed consent, privacy, anonymisation and balancing these issues with the benefits of using big data for the common good [60]. Digital technologies give users the option to control their data by allowing or revoking access to their data by opting in or out. However, personal data collected using digital means also have the risk of being accidentally or maliciously manipulated, shared or abused [61]. Researchers using emerging technologies should be cognizant of these issues and work with ethicists and Institutional Review Boards to ensure the privacy and confidentiality of users.

Some GoPro camera models contain Global Positioning System (GPS), accelerometer, and gyroscope instrumentation and are capable of measuring and recording position, velocity, acceleration, and inertial data, however our study did not capture these raw data. Information on routes such as distance, speed, elevation, origin, and destination can allow researchers to conduct a detailed investigation on substantially larger samples of PA behaviour and BEs across widespread geographic locations in the future. Specifically, these technologies offer significant potential to improve study designs and methods for natural experiments, longitudinal studies, and intervention research in the future.

4.7. Recommendations for Future Research

Taking into consideration these limitations, heterogenous mixed-methods research that incorporates wearable technologies with traditional data collection methods can improve monitoring of real-time information for urban planning [62,63]. Overall, the unobtrusive nature of data from wearable sensors provides a robust method to explore the influence of

outdoor environments on behaviours such as PA. By incorporating emerging technologies, PA promotion and measurement efforts may be able to achieve greater precision. This hypothesis would need further testing, across a range of different environmental contexts, such as dense urban environments, green and blue spaces, and in different populations, such as young people, older adults, or people living with disabilities.

5. Conclusions

This article set out to illustrate how chest-mounted GoPro cameras can complement and offer insights into the use of photo elicitation and other complementary elicitation techniques.

Providing and promoting safe, equitable, and inclusive access to parks, trails, recreation areas, and green spaces can influence community health and increase physical activity. However, the objective study of green space features and their impacts on physical activity behaviours is challenging. Traditional methods such as in-person observations, audits, and surveys are time, labour and cost intensive, and only provide a limited cross-sectional view of PA behaviour at a specific point in time. Data from our study suggest that using wearable technology can provide valuable insights for understanding urban green space use and preferences. Specifically, our study illustrates the methodological advantages of emerging technologies because they can (i) perform continuous, objective, and long-term evaluation of green spaces, (ii) help monitor green space use on a fine temporal resolution throughout the day, and (ii) provide a cost-effective source of information about popular and emerging leisure time activities. Evidence from our study indicates that the use of GoPro video footage in combination with elicitation interviews can provide a valuable context in situ to capture more authentic perceptions of outdoor spaces.

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