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Effects of climate change awareness on green purchase behaviour, biking, and walking time: moderated mediation by sustainability knowingness

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ABSTRACT

Walking and biking are central to the growing health-sustainability debate for favouring the planet and protecting individuals against disease. Research has shown that environmental knowledge factors such as Climate Change Awareness (CCA) and Sustainability Knowingness (SK) can positively influence pro-environmental behaviours [e.g., Green Purchase Behaviour (GPB)]. However, no study has tested the effect of CCA and SK on bicycling (biking) and walking time. This study, therefore, investigated whether there is a moderated mediation by SK in the association of CCA with GPB, walking, and biking time. A cross-sectional design characterised by common methods bias assessment and sensitivity analyses was utilised. The participants were 830 adult residents in Accra, Ghana (mean age = 30 years). Data were collected with standardised scales and analysed with Hayes' Process Model through structural equation modelling. A positive direct effect of CCA on GPB ($\beta = 0.26$; $p < 0.001$) and biking ($\beta = 0.13$; $p < 0.001$), as well as walking time ($\beta = 0.16$; $p < 0.001$), was found. GPB had a positive effect on biking time ($\beta = 0.10$; $p < 0.001$) but a negative effect on walking time ($\beta = -0.093$; $p < 0.001$). CCA had a positive effect on biking time but a negative indirect effect on walking time through GPB. There was evidence of a moderated mediation in the sense that the indirect effects of CCA on biking and walking were stronger with higher SK. Individuals with higher CCA are more likely to perform GPB and biking, especially with higher SK.

1. Introduction

Climate change poses a serious environmental challenge because it accompanies incidences (e.g., flooding, and extreme weather) that threaten the conviviality of neighbourhoods. Flooding and storms are prevalent climate change incidences that often exterminate public infrastructure and spaces (e.g., parks and streets), thereby making the neighbourhood less supportive of health-seeking behaviours (e.g., physical activity and social engagement). Undoubtedly, public health is threatened by climate change, which is why the health-sustainability

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debate (Asiamah et al., (2023a); Danquah & Asiamah, 2022) is gaining momentum. This debate is, in part, an academic voice emphasizing the health implications of climate change and sustainability campaigns, and advocates efforts toward a safer planet (Asiamah et al., (2023a); Danquah & Asiamah, 2022; Opuni et al., 2022). The climate crisis is partly due to carbon emissions from transportation involving the combustion of fossil fuels (Asiamah et al., (2023a)). A growing body of research recognises walking and bicycling (or biking) as the most environment-friendly types of transportation because they produce no or little carbon footprint (Asiamah et al., (2023a); Oliver et al., 2014).

Researchers (Asiamah et al., (2023a); Opuni et al., 2022) recognise pro-environmental behaviours as the ultimate ways individuals can contribute to a safer planet. Pro-environmental behaviours refer to conscious actions or choices made by individuals and manufacturers to avoid or minimise the adverse impact of their daily activities on the environment (Marshall et al., 2013; Opuni et al., 2022). Walking to a grocery shop is a type of pro-environmental behaviour because it produces no or negligible carbon footprint (Asiamah et al., (2023a)). Green Purchase Behaviour (GPB) is another type of pro-environmental behaviour that encapsulates actions and choices that are cognizant of the public consequences of private consumption and employs purchasing power to bring about a social change (Joshi & Rahman, 2015). It is a form of socially responsible consumption that boosts consciousness toward environmental degradation.

Two determinants of pro-environmental behaviours reported in the literature are Climate Change Awareness (CCA) and Sustainability Knowingness (SK), both of which we subsequently refer to as environmental knowledge indicators since researchers (Bong Ko & Jin, 2017; Joshi & Rahman, 2015; Moslehpour et al., 2023) recognise them as measures of environmental knowledge. CCA has been defined as the extent to which manufacturers relate to, understand, and prioritise climate change as a driver of change (Marshall et al., 2013). We define CCA as the extent to which the individual knows about climate change and its incidences (e.g., global warming) and what can be done to avoid them. We adopt this definition because it identifies CCA as an individual factor and agrees with our measurement of CCA. SK is the experience or awareness of sustainability phenomena (Marcos-Merino et al., 2020). It is the individual's knowledge of personal responsibilities, public efforts, and campaigns to achieve sustainability in response to climate change (Marcos-Merino et al., 2020; Opuni et al., 2022). While CCA is predominantly about knowledge of climate change as a problem, SK is knowledge of what should be done to address climate change.

Research to date has confirmed a positive association between environmental knowledge indicators and pro-environmental behaviours. For example, a cross-sectional study in Taiwan found a positive effect of environmental knowledge on green purchase intention, a domain of GPB (Moslehpour et al., 2023). In a cross-sectional study undertaken in the United States, environmental knowledge had a positive effect on the purchase of green products (Bong Ko & Jin, 2017). This result has been confirmed in studies conducted in India as well (Jaiswal & Kant, 2018; Joshi & Rahman, 2015), and two cross-sectional studies (Danquah et al., 2022; Opuni et al., 2022) have found a positive correlation between environmental knowledge indicators (i.e., CCA and SK) and socially responsible consumption behaviour, which is analogous to GPB. However, no study has examined the potential link between specific environmental knowledge factors (i.e., CCA and SK) and walking as well as biking for transportation.

To advance the above evidence, we investigated whether the potential indirect effect of CCA on biking and walking through GPB is moderated by SK. We examined this relationship for the first time for theoretical reasons delineated later and in our response to the non-availability of empirical studies linking environmental knowledge indicators to walking and biking. Testing this moderated mediation based on a sample of city dwellers is novel for some reasons. Although city dwellers may be willing to walk for transportation, their circumstances may compel them to utilize faster transportation types that are not necessarily environment friendly. City residents usually live far from their regular destinations (e.g., workplaces), so they may choose biking (i.e., a faster transportation type suited for larger communities) over walking though they may know walking is better for the planet. If so, environmental knowledge indicators and GPB may not affect walking and biking in the same way, specifically within a moderated mediation model.

Walking and biking are active forms of transportation (Asiamah et al., (2023a); Mandal et al., 2023; Musau et al., 2023; Pucher et al., 2010), but whether the two are differently influenced by environmental knowledge indicators and pro-environmental behaviours (e.g., GPB) among residents in a city has not been investigated. Practitioners and researchers may consequently wrongly assume that environmental knowledge indicators and GPB have a positive effect on both walking and biking. This potentially wrong assumption can misguide the design of future research and policies in response to climate change. Walking is the most environment-friendly type of transportation (Asiamah et al., (2023a)); hence, an understanding of how this transport behaviour, compared to biking, is affected by environmental knowledge indicators and GPB in a moderated mediation context can inform future research, city design, and climate change interventions.

2. Theoretical framework

Pro-environmental behaviours occupy a central place in efforts against climate change and its incidences such as flooding, ocean acidification, and rising sea levels. For this reason, a globally upheld pathway to a cleaner and safer planet is enabling individuals to value and practice pro-environmental behaviours. There is a growing consensus among scholars (Baiardi & Morana, 2021; Danquah et al., 2022; Gönen et al., 2023) that public education that improves people's understanding of climate change and sustainability agenda is necessary for positive pro-environmental behaviour change. This consensus informed the theoretical foundation of the moderated mediation tested in this study. We lay this foundation on the Tripartite Integrated Model of Social Influence (TIMSI) originally formulated by Mica Estrada and colleagues (Estrada et al., 2011). This model is a framework explaining the relationship between climate change knowledge acquisition and environment-friendly behaviours.

The TIMSI posits that climate change education provides knowledge that acts as a catalyst for integrating young individuals into a community of residents who care about the consequences of climate change (Estrada et al., 2017). Climate change education from this perspective encompasses all efforts or campaigns that improve people's knowledge of climate change and its individual, national, and global interventions. Environmental activism, incorporation of climate change and sustainability topics in formal educational curricula, and sustainability campaigns on the media are common approaches within this education. Increasing awareness about climate change (Iturriza et al., 2020; Venghaus et al., 2022) may have heralded a social climate where many people have acquired environmental knowledge. Thus, the TIMSI implies that climate change education can enhance environmental knowledge indicators such as CCA and SK.

A noteworthy dimension of the TIMSI is the concept of *community integration* (Estrada et al., 2011, 2017), which emphasizes that people who receive climate change education care about the consequences of climate change. For such individuals, environmental knowledge (e.g., CCA and SK) catalyses successful integration into the community. Community integration can occur through pro-environmental behaviours driven by one's willingness to minimise the environmental consequences of private consumption. For example, people with CCA and SK are more likely to perform environment-friendly behaviours, which are implicit in GPB. Mobility options (e.g., walking and biking) are the primary means by which people get integrated into the community (Asiamah et al., (2023a); Frank et al., 2010), suggesting that environmental knowledge from climate change education can encourage walking and biking in the community integration of individuals who are concerned about climate change and are keen to minimise the environmental consequences of everyday life.

Environmental knowledge as a catalyst of behaviour change in response to climate change has three tenets: *self-efficacy, self-identity,* and *values* (Estrada et al., 2011, 2017). Self-efficacy is a belief in one's ability to take a desired course of action in the interest of a safer and cleaner environment. People with higher self-efficacy are more likely to perform pro-environmental behaviours based on their CCA and SK. Self-identity is a recognition of the community as a part of the individual, which encourages behaviours that protect the community or environment. Values are guiding principles that involve sharing community goals, aspirations, and norms. People who uphold these values are usually inclined to perform behaviours that protect the social and physical environments in a spirit of altruism and environmentalism. Within the remit of TIMSI, self-efficacy, self-identity, and values are the normative drivers of pro-environmental behaviours in the interest of a safer planet.

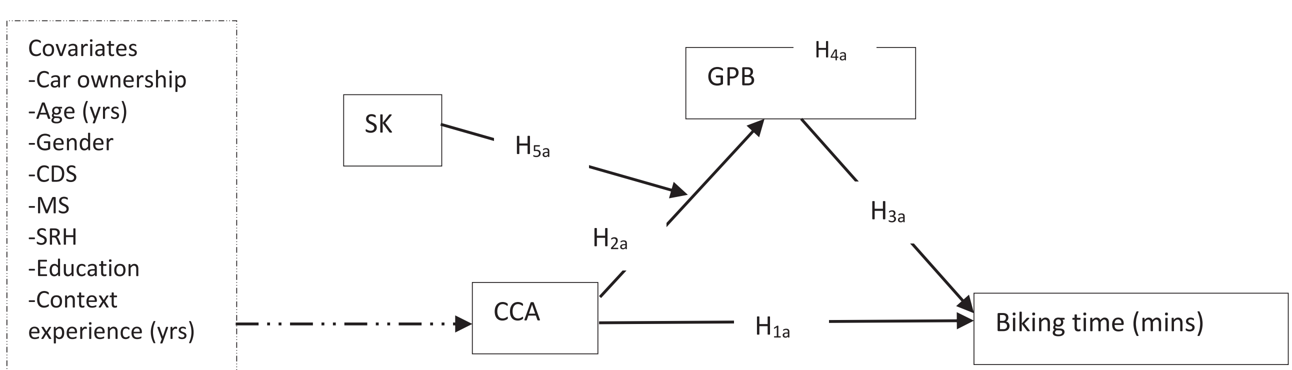
Congruent with the TIMSI is the Knowledge Deficit Model (Plutzer & Hannah, 2018), which asserts that increased knowledge results in behaviour change and action. The model adds that knowledge is a precondition for action, implying that environmental knowledge is a precursor of pro-environment behaviour (e.g., GPB, walking, and biking). SK and CCA as environmental knowledge indicators would accompany cognisance of walking and biking as environment-friendly types of mobility or channels of community integration (Asiamah et al., (2023b); Larouche et al., 2014), which is why they are likely to be associated with higher walking and biking behaviour. Fig. 1a (biking model) and Fig. 1b (walking model) illustrate our two moderated mediation models based on the above theoretical deductions.

Drawing on the above analysis of the TIMSI and Knowledge Deficit Model, CCA would have a positive effect on biking (hypothesis 1a; H1a) and walking (hypothesis 1b; H1b) in the sense that individuals with higher CCA would spend more time biking or walking for transportation. Since GPB embodies environment-friendly actions (Dangelico et al., 2021; Estrada et al., 2017; Kanchanapibul et al., 2014), it is likely to be higher among individuals with higher CCA in biking (hypothesis 2a; H2a) and walking (hypothesis 2b; H2b) models. If GPB is positively influenced by CCA, it can be expected to have a positive influence on biking (hypothesis 3a; H3a) and walking (hypothesis 3b; H3b), which means that people with higher GPB would spend more time biking and cycling for transportation. In both models, GPB can mediate the effect of CCA on biking (hypothesis 4a; H4a) and walking (hypothesis 4b, H4b).

SK and CCA are unique but complementary environmental knowledge indicators because the latter is about climate change and actions against it (Baiardi & Morana, 2021; Gönen et al., 2023), whereas the former is about sustainability and efforts in favour of it (Marcos-Merino et al., 2020; Opuni et al., 2022). As such, they can interact on GPB in the biking (hypothesis 5a; H5a) and walking (hypothesis 5b; H5b) models, implying that the strength of the effect of CCA on GPB would vary across levels of SK. This interaction effect forms the basis of the moderated mediation, which means the indirect effects of CCA on biking and walking through GPB would vary across levels of SK. In a relatively large city, nonetheless, people with high CCA and GPB are likely to spend less time walking while they spend more time biking. This behaviour would be compulsive for residents who want to walk but are compelled to bike or drive because their destinations are not within walking distance. From this viewpoint, GPB and CCA are likely to have a negative effect on walking but a positive effect on biking among city residents.

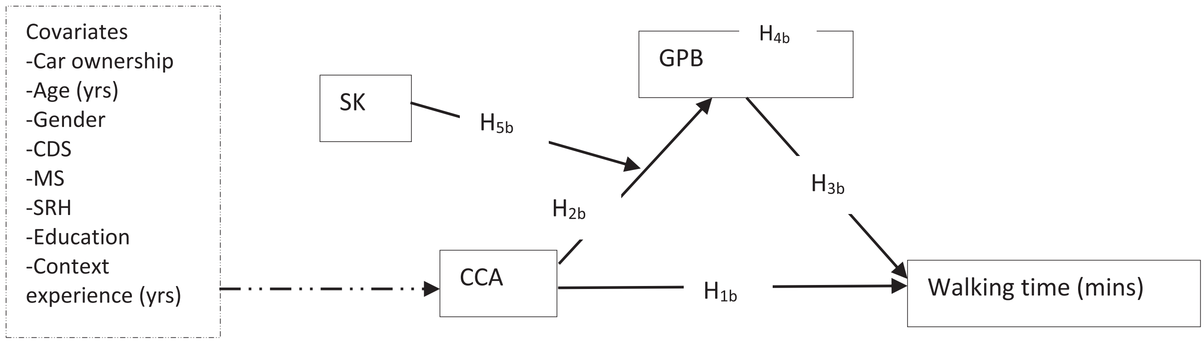
Further to the above, CCA may be influenced by residents' previous experience of climate change events. Flooding and unexpected rainfalls, for example, are episodic events that influence transportation choices (Arnall, 2021; Bundy et al., 2023). During the raising season, people with a high level of CCA may spend less time walking to avoid dangers posed by floods and unexpected rainfalls. Walking in contexts experiencing extreme temperatures (e.g., heatwaves) would be daunting, so residents with high CCA may not walk in such contexts. Even so, residents may be more sensitive to flooding, compared to heatwaves, since injuries, losses, and mortality from floods can occur instantly whereas heatwaves would usually impact people gradually and cause deaths in the long-term. Residents can adapt to or cope with the long-term impacts of heatwaves but are unlikely to do so during devastating floods in which homes and properties are submerged or swept away. Thus, floods and other episodic events, compared to heatwaves, are more likely to prevent residents with high CCA from walking in the short-term. This phenomenon is owing to flooding, compared to heatwaves, requiring higher adaptive capacity in the short-term.

According to the Disengagement Theory of Ageing, people lose the capacity to perform social and physical activities as they age (Asiamah, 2017). The DTA adds that people lose the ability to adapt to changing life conditions partly owing to a gradual decline in their functional capacity and personal resources (e.g., income and social networks). It can, thus, be inferred that people lose adaptive capacity or the ability to cope with floods, heatwaves, and other harsh weather conditions as they become older. Suffice it to say that people would not be able to maintain their adaptive capacity against climatic events for the long-term. This situation is problematic because heatwaves, for example, would require



Note: SK – sustainability knowingness; CCA – climate change awareness; GPB – green purchase behaviour; CDS – chronic disease status; MS – marital status; SRH – self-reported health; CDS – chronic disease status, MS – marital status, SRH – self-reported health. H1a – the effect of CCA on biking time; H2a – the effect of CCA on GPB; H3a – the effect of GPB on biking time; H4a – GPB mediates the effect of CCA on biking time; H5 – the moderating role of sustainability knowingness in the effect of CCA on GPB; H5a (not shown in the figure) – moderated mediation by sustainability knowingness.

Fig. 1a. A framework of the moderated mediation model (biking time).

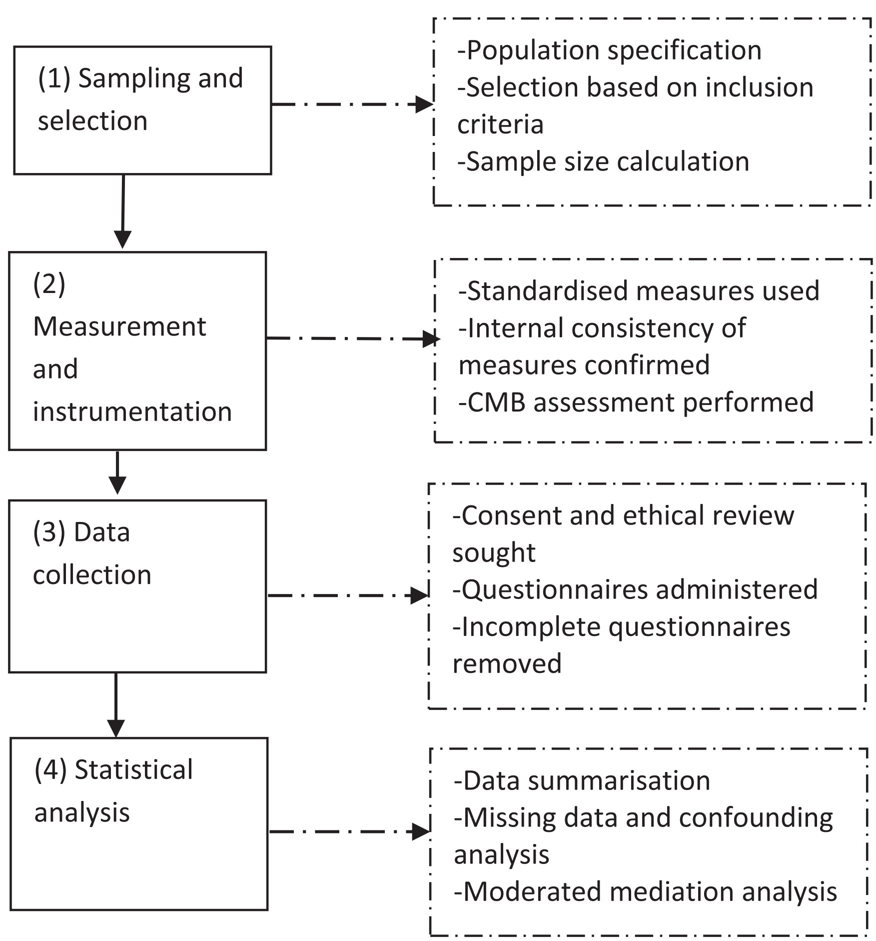


Note: SK – sustainability knowingness; CCA – climate change awareness; GPB – green purchase behaviour; CDS – chronic disease status; MS – marital status; SRH – self-reported health; CDS – chronic disease status, MS – marital status, SRH – self-reported health. H1a – the effect of CCA on walking time; H2a – the effect of CCA on GPB; H3a – the effect of GPB on walking time; H4a – GPB mediates the effect of CCA on walking time; H5 – the moderating role of sustainability knowingness in the effect of CCA on GPB; H5a (not shown in the figure) – moderated mediation by sustainability knowingness.

Fig. 1b. A framework of the moderated mediation model (walking time).

more sustained adaptive capacity since their impacts would last for an extended period. This viewpoint implies that climatic events that have a long-term impact on residents would discourage walking behaviour for a longer period and people may not be able to perform adaptive behaviour to walk amidst these events.

The literature suggests several factors (e.g., education, and age) can predict environmental knowledge indicators. Education, for example, is one of the channels for acquiring climate change knowledge (Jeong et al., 2021; Lee et al., 2015), suggesting that the effects of CCA and sustainability knowledge on GPB, biking, and walking can be due to higher education. Walking and biking require significant physical strength, so older adults (compared with younger people) are less likely



Note: CMB – common methods bias

Fig. 2. Flowchart of the research methodology.

to perform them with higher environmental knowledge and GPB. Thus, the effects in the moderated mediation models may be confounded by age, education, and other factors shown in Fig. 1a and Fig. 1b. To avoid under or over-estimating the effects, adjusting for these potential covariates in compliance with the STROBE (i.e., Strengthening the Reporting of Observational Studies in Epidemiology) checklist was necessary.

3. Methods

3.1. Design

This study adopted a STROBE-compliant cross-sectional design comprising sensitivity analyses and procedures against common methods bias. Fig. 2 is a flowchart of the design adopted.

3.2. Participants and selection

The participants were permanent residents of Accra, Ghana's largest and sprawling city (Engstrom et al., 2013). The selection criteria were: (1) being able to walk independently for at least 10 min; (2) having a minimum of basic education instructed in English, which we used as an indicator of the ability to complete surveys in English; (3) being aged at least 18 years, and (4) willingness and availability to complete the survey. The first criterion was applied to ensure that all participants could walk and perform other physical tasks independently. Potential participants were interviewed with a checklist based on the above criteria and invited to participate in the study at supermarkets, shopping malls, and community centres. A total of 1090 individuals met the above inclusion criteria and were included in the study. We calculated the minimum sample necessary with the Daniel Soper's sample size calculator for Structural Equation Modelling (SEM). This tool has become a reliable sample size calculator for SEM (Adedeji et al., 2016; Zewdie et al., 2022), and was based on recommended statistics (i.e., moderate effect size = 0.3; power = 0.8; α = 0.05). The sample size reached with the above tool was 589, but we gathered data on all 1090 participants to maximise the statistical power of our tests.

3.3. Variables and measurement

We measured CCA with a 17-item standard scale with its five descriptive anchors (i.e., 1 – strongly disagree, 2 – disagree, 3 – somewhat agree, 4 – agree, and 5 – strongly agree). This tool was adopted from a previous study (Gönen et al., 2023) and produced satisfactory internal consistency in the form of Cronbach's α = 0.74, a value that exceeds the minimum recommended value (Gönen et al., 2023; Nagarkar et al., 2014). To adapt this scale for an African context, we replaced its original climate change phenomena reported for contexts experiencing extreme winter with phenomena experienced in Ghana. This adaptation necessitated an assessment of the factor structure of the scale with exploratory factor analysis, which yielded satisfactory results including factor loadings ≥0.5 (Ng, 2013) and a total variance of 61.2%. Appendix A1 shows items of the adapted scale. Scores on the scale obtained through parcelling (summation) range from 17 to 65, with larger scores indicating higher CCA.

SK was measured with a 9-item standard scale with five descriptive anchors (i.e., strongly disagree – 1; disagree – 2; somewhat agree – 3; agree – 4, and strongly agree – 5). This measure was adopted in whole from an existing study (Marcos-Merino et al., 2020) and produced satisfactory Cronbach's α = 0.73. Scores on the scale range from 9 to 45, with larger scores indicating higher SK. Appendix A2 shows items of this tool. GPB was measured with a 5-item actual green purchase sub-scale adopted in whole from an existing study (Kanchanapibul et al., 2014) with its five descriptive anchors (i.e., 1 – strongly disagree, 2 – disagree, 3 – somewhat agree, 4 – agree, and strongly agree – 5). This sub-scale was chosen because it measures actual green purchase instead of purchase intention. Green purchase intention does not necessarily translate into actual purchase, so it is not as environmentally friendly as actual purchase. The scale yielded a satisfactory Cronbach's α = 0.72 and had scores ranging from 5 to 25, with larger scores indicating higher GPB. Appendix A3 shows its items. Negative items in all measures were reverse-coded.

Walking and biking time were measured as discrete variables. We followed a previous study (Bempong and Asiamah, 2022) to measure walking time (1) in recreation or social engagement; (2) in economic activity, and (3) for health-seeking purposes. We preferred this method because it captured time spent on specific daily activities and, therefore, minimised memory bias. Walking for recreation and social engagement were measured by asking participants to report time (in minutes) spent on a typical day walking to visit people, participate in social events, and enjoy recreation. Walking in economic activity was measured by asking participants to report time spent on a typical day in walking for an economic activity such as going to the market, supermarket, or similar places to shop or sell. Finally, walking for health was measured by asking the participants to report time spent on a typical day walking for maintaining or improving health. We added time reported on the three activities to generate data on walking time. We followed the same procedure to measure biking time.

Following previous research (Asiamah et al., 2023b; Danquah et al., 2022; Opuni et al., 2022; Sghaier et al., 2022), nine covariates were measured. Five of the covariates (i.e., sex, marital status, chronic disease status, car ownership, and self-reported health) were measured as categorical variables. Chronic disease status was measured by asking the participants to report the number of chronic conditions they had. The responses in this regard were coded into a dichotomous variable (i.e., none – 1, and one or more – 2). Self-reported health was measured by asking the participants to indicate whether their health was poor or good and the responses were put into two categories (i.e., poor – 1, and good – 2). Car ownership was measured by asking the participants to indicate whether they owned and routinely drove a private car and the responses were coded into two groups (i.e., no – 1, and yes – 2).

Sex (coded 1 for "men" and 2 for "women") and marital status (coded 1 for "not married" and 2 for "married") were also measured as dichotomous categorical variables. The categorical variables were coded into dummy-type variables for our statistical analysis. Income, age, context experience, and education were measured as discrete variables. Income was measured as the individual's gross earnings in Ghana cedis. We operationally defined context experience as how long the individual had lived in their neighbourhood. We assumed that residents with more context experience would be more familiar with their neighbourhoods and are, therefore, more likely to walk or bike. We measured context experience by asking the participants to report how long (in years) they had lived in their current neighbourhood. Finally, education was measured by asking participants to report their years of schooling.

3.4. Instrumentation

Data were collected with a self-reported questionnaire with three blocks of information. In the first block, we presented the aim of the study, the ethical statement, and general instructions for completing the questionnaire. The second block presented measures on the main variables (i.e., CCA, GPB, SK, walking time, and biking time) as well as specific information for completing this section. In the third section, demographic variables and covariates were presented. The organization of the questionnaire was informed by previous measures (Kock et al., 2021) to avoid or minimise common methods bias. We provided specific instructions for completing each block or section, enabling the participants to respond in the right context. Harman's one-factor method (Kock et al., 2021; Sghaier et al., 2022) was utilised to ascertain whether there was common methods bias in the data. In this vein, exploratory factor analysis with varimax rotation was employed to assess the factor structures of the psychometric measures or scales. Common methods bias is absent if each measure produces two or more factors or a variance ≤40% on each factor extracted (Kock et al., 2021). This condition was met for all psychometric measures (i.e., CCA, GPB, and SK), which evidenced the absence of common methods bias in the data. CCA (variance of first factor = 20.4%), GPB (variance of first factor = 40.9%), and SK (variance of first factor = 33.2%) yielded four, two, and three factors respectively.

3.5. Data collection

Ethical review and clearance were received from the institutional ethics committee of the Africa Centre for Epidemiology (Number 004-08-2023-ACE). The participants provided written informed consent after reading the study's aim, importance, and potential risks. Four trained research assistants supported data collection at the supermarkets, shopping malls, and community centres where the participants were recruited. The participants were allowed to return completed questionnaires in two weeks through a private courier. All the participants were guided by the research assistants to complete the questionnaire accurately, and data collection was completed over five weeks between August and September 2023. Out of 1090 questionnaires administered, 844 were returned by the participants, and 830 were analysed. We discarded 14 returned questionnaires because they were filled halfway, making it impossible for at least three of their variables to be represented in the analysis.

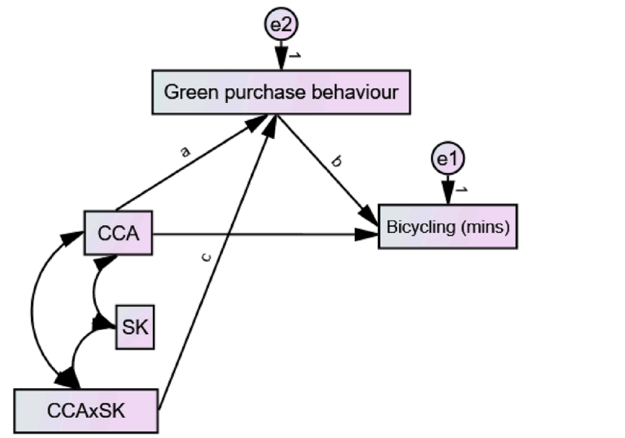
3.6. Statistical analysis approach

Data were analysed in two phases. In the first phase, the data were summarised, missing data were identified, and a sensitivity analysis for confounding variables was performed with SPSS 28 (IBM Inc., New York, USA). In the second phase, the moderated mediation model was fitted with Amos 28 and Hayes' Process Model through structural equation modelling.

We summarised the data with descriptive statistics (averages and counts), enabling us to identify missing data. Chronic disease status, marital status, and car ownership were the only variables with missing data. On each of these variables, the missing data were less than 3 % and randomly distributed. Following previous research (Rezai et al., 2009; Sghaier et al., 2022), therefore, we performed the sensitivity analysis for the ultimate confounding variables with the missing data. In the confounding analysis, we followed a standard statistical procedure (Rezai et al., 2009; Sghaier et al., 2022) to screen for only variables likely to confound the primary effects of the moderated mediation model. With this technique, we avoided infusing in the model measured covariates that have no or little influence on the effects. Appendix B shows the steps taken in this sensitivity analysis in which two variables (i.e., age, and chronic disease status) were selected as the ultimate covariates for both models.

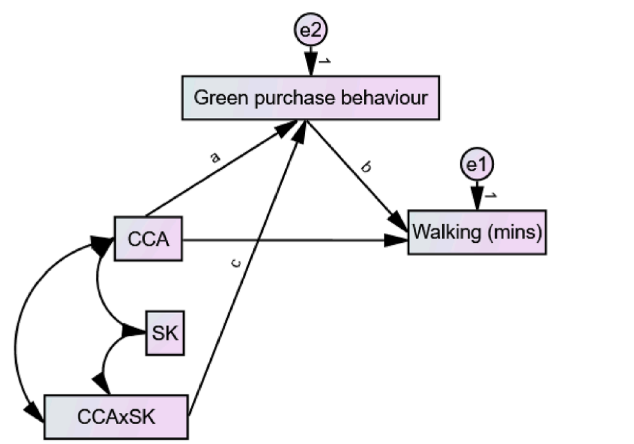
In the second phase, we fitted two baseline models without the ultimate covariates. In the first baseline model, SK was treated as a moderator of the indirect effect of CCA through GPB on biking time (see Fig. 3a). In the second model, biking time was replaced with walking time (see Fig. 3b). Subsequently, two ultimate (adjusted) models incorporating the ultimate covariates were fitted. In assessing moderated mediation, we computed an interaction term (i.e., CCAxSK) by first centring SK and computing the product of the centred variable and CCA based on the Hayes' Process (Clement & Bradley-Garcia, 2022; Hayes, 2018). The Simple Slope (SS), Conditional Indirect Effect (CIE), and Index of Moderated Mediation (InModMed) were computed with a 2000 biased-corrected sampling iterations or bootstraps at a 95 % confidence interval. The basic path coefficients (i.e., a, b and c; see Fig. 3a and Fig. 3b) were generated through fitting the models. Appendix C shows the formulas used to estimate the indexes at three levels (i.e., low, medium, and high) of the moderator variable.

In a second sensitivity analysis, we compared the baseline (non-adjusted) and ultimate models to assess any changes in effect sizes due to the ultimate covariates. We performed this complementary analysis to assess the potential impact of the covariates. The conclusions of this study are based on the ultimate models. The moderating effect of SK on the relationship between CCA and GPB was plotted, and the resulting figure showed the effects of CCA on GPB at two levels (i.e., low, and high) of SK. The statistical significance of the effects was detected at a minimum of $p < 0.05$.



Note: CCC – climate change awareness; SK – sustainability knowingness

Fig. 3a. The statistical moderated mediation model (bicycling).



Note: CCC – climate change awareness; SK – sustainability knowingness

Fig. 3b. The statistical moderated mediation model.

4. Results

In Table 1, about 37 % ($n = 305$) of the participants were men, and the average age of the participants was about 30 years (Mean = 29.6; SD = 6.41). The average CCA was about 57 (Mean = 57.23; SD = 6.38) whereas the average walking time was about 121 min (Mean = 120.52; SD = 95.68). After adjusting for the ultimate covariates (see Table 2), CCA had a positive effect on GPB ($\beta = 0.26$; $p < 0.001$) and biking time ($\beta = 0.13$; $p < 0.001$). This result means that higher CCA was associated with higher GPB and biking time. GPB had a positive effect on biking time ($\beta = 0.10$; $p < 0.001$), suggesting that higher GPB was associated with higher biking time. The interaction between CCA and SK on biking time was significant ($\beta = 0.33$; $p < 0.001$). In the adjusted model for walking, CCA had a positive effect on GPB ($\beta = 0.26$; $p < 0.001$) and walking time ($\beta = 0.16$; $p < 0.001$). Thus, higher CCA was associated with both GPB and walking time. CCA had a positive indirect effect through GPB on biking time ($\beta = 0.03$; $p < 0.01$) but a negative indirect

Table 1
Summary statistics on variables included (n = 830).

Variable	*M*	*SD*	Range	n(%)
Sex				
Men				305(36.70 %)
Women				525(63.30 %)
Chronic disease status				
None				680(81.90 %)
One or more				150(18.10 %)
Missing				20(2.30 %)
Marital status				
Not married				385(46.40 %)
Married				435(52.40 %)
Missing				10(1.20 %)
Self-reported health				
Poor				35(4.20 %)
Good				775(93.40 %)
Missing				20(2.40 %)
Car ownership				
No				650(78.30 %)
Yes				175(21.10 %)
Missing				5(0.60 %)
Income (₵)	1388.23	1626.98	200–9800	
Age (yrs)	29.60	6.41	19–48	
Context experience (yrs)	5.71	3.00	1–15	
Education (yrs)	16.73	5.11	12–19	
Climate change awareness	57.23	6.38	41–79	
Sustainability knowingness	31.86	4.30	23–45	
Green purchase behaviour	17.14	3.43	0–25	
Walking time (mins)	120.52	95.68	0–990	
Bicycling time (mins)	25.17	55.34	0–390	

Note: M – mean; SD – standard deviation; n – frequency.

effect on walking time ($\beta = -0.03$; $p < 0.01$).

In Table 3, all estimates of the simple slope were significant at $p < 0.001$ for both biking and walking, which indicates that the effect of CCA on GPB varied across levels of SK. In addition, all estimates of conditional indirect effect were significant at $p < 0.001$ for the biking and walking models. While the estimates of biking are positive, those of walking are negative, suggesting that the indirect positive effect of CCA on biking (through GPB) was stronger at higher SK whereas the negative effect on walking time was stronger at higher SK. We found evidence of a moderated mediation for biking (parameter = 0.008, $p < 0.01$) and walking (parameter = -0.012, $p < 0.01$).

In Table 4, only the baseline model for biking produced satisfactory fit indexes, including the Chi-square test (statistic = 1.119; $p > 0.05$). Fig. 4 shows the interaction between CCA and SK on GPB; the effect of CCA on GPB was stronger at higher SK in both the biking and walking models.

5. Discussion

This study investigated whether there is a moderated mediation by SK in the association of CCA with GPB, walking, and biking time. The study found a positive effect of CCA on both biking and walking time, which confirms the first set of hypotheses (H1a and H1b) and suggests that individuals with higher CCA reported more time for walking and biking. This evidence is supported by the TIMSI and knowledge deficit

Table 3
Estimates of simple slopes, conditional indirect effects, and index of moderated mediation (n = 830).

Parameter	Standardised effect (β) Biking time (mins)	95 % CI	Standardised effect (β) Walking time (mins)	95 % CI
Estimates of simple slopes				
lowSS	0.115**	±0.078	0.115**	±0.078
MedSS	0.139**	±0.075	0.139**	±0.075
highSS	0.154**	±0.073	0.154**	±0.073
Estimates of conditional indirect effects				
lowCIE	0.197*	±0.281	−0.305*	±0.486
medCIE	0.238*	±0.330	−0.369*	±0.583
highCIE	0.263*	±0.365	−0.408*	±0.647
Index of moderated mediation				
InModMed	0.008*	±0.010	−0.012*	±0.021

** $p < 0.001$; *$p < 0.01$; CI – confidence interval; SS – simple slopes; CIE – conditional indirect effects.

Table 2
Effects of climate change awareness on biking time and walking time through green purchase behaviour (n = 830).

Outcome variable	Path	Predictor	Direct effects B	SE (of B)	CR	β	Indirect effects B	β
Biking model								
Baseline (non-adjusted)								
Green Purchase Behaviour	<—	Climate Change Awareness	0.136	0.017	7.863	0.254**		
Biking time (mins)	<—	Climate Change Awareness	1.125	0.315	3.572	0.130**	0.233*	0.027*
Biking time (mins)	<—	Green Purchase Behaviour	1.711	0.586	2.921	0.106**		
Green Purchase Behaviour	<—	CCAxSK	0.004	0.000	9.568	0.311**		
Ultimate (adjusted)								
Green Purchase Behaviour	<—	Climate Change Awareness	0.135	0.017	8.128	0.256**		
Biking time (mins)	<—	Climate Change Awareness	1.125	0.306	3.679	0.130**	0.230*	0.027*
Biking time (mins)	<—	Green Purchase Behaviour	1.711	0.583	2.936	0.104**		
Green Purchase Behaviour	<—	CCAxSK	0.005	0.000	10.49	0.331**		
Climate Change Awareness	<—	Age	0.134	0.036	3.753	0.135**		
Climate Change Awareness	<—	Chronic Disease Status	−2.254	0.596	−3.783	−0.136**		
Walking model								
Baseline (non-adjusted)								
Green Purchase Behaviour	<—	Climate Change Awareness	0.124	0.016	7.721	0.243**		
Walking time (mins)	<—	Climate Change Awareness	2.176	0.508	4.281	0.154**	−0.372*	−0.026*
Walking time (mins)	<—	Green Purchase Behaviour	−3.009	0.997	−3.018	−0.108**		
Green Purchase Behaviour	<—	CCAxSK	0.005	0.000	10.985	0.345**		
Ultimate (adjusted)								
Green Purchase Behaviour	<—	Climate Change Awareness	0.135	0.017	8.128	0.256**		
Walking time (mins)	<—	Climate Change Awareness	2.366	0.532	4.445	0.158**	−0.375*	−0.024*
Walking time (mins)	<—	Green Purchase Behaviour	−2.652	1.015	−2.614	−0.093**		
Green Purchase Behaviour	<—	CCAxSK	0.005	0.000	10.49	0.331**		
Climate Change Awareness	<—	Age	0.134	0.036	3.753	0.135**		
Climate Change Awareness	<—	Chronic Disease Status	−2.254	0.596	−3.783	−0.136**		

** $p < 0.001$; *$p < 0.01$; B – unstandardised effect; β – standardised effect; SE – standard error; CR – critical ratio; CCA – climate change awareness; SK – sustainability knowingness.

Table 4
Fit indices from the four models (n = 830).

Index	Model			
	Biking time (mins)		Walking time (mins)	
	Baseline	Adjusted	Baseline	Adjusted
Chi-square	1.119	220.87**	48.693**	272.08**
Goodness of fit index	0.999	0.936	0.979	0.917
Tucker-Lewis index	1.000	0.914	0.960	0.894
Root Mean Square Error of Approximation	0.000	0.139	0.133	0.155
Akaike Information Criterion	27.119	250.866	72.693	302.08

** $p < 0.001$.

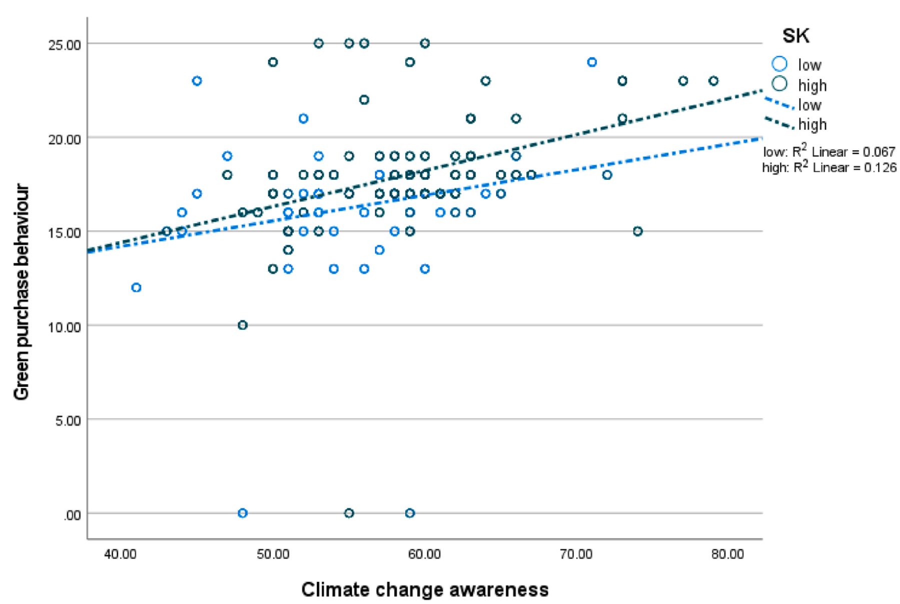
model, both of which assert that environmental knowledge implicit in CCA may encourage environment-friendly behaviours (Estrada et al., 2017). The literature recognises biking and walking as some of the best pro-environmental mobility options (Asiamah et al., (2023a); Frank et al., 2010; Rothman et al., 2018), implying that public education programmes improving CCA may encourage environment-friendly travel. Research to date has reported a positive effect of biking and walking on health (Fritschi et al., 2012; Oja et al., 2011; Tschentscher et al., 2013), which means that the positive effect of CCA on walking and biking can be extended to health outcomes. It can be inferred that individuals who spend more time biking and walking for transportation owing to their CCA are likely to report better health, but to better consolidate the ongoing health-sustainability debate, future studies assessing this potential relationship are needed.

We further found a positive effect of CCA on GPB, which supports the second set of hypotheses (H2a and H2b) and indicates that residents with higher CCA reported higher GPB. This result is consistent with results from studies reported earlier (Bong Ko & Jin, 2017; Jaiswal & Kant, 2018; Joshi & Rahman, 2015; Moslehpour et al., 2023), which complements the argument of the TIMSI that environmental knowledge such as CCA can encourage socially responsible consumption (e.g., green purchase behaviour) among residents. The above related results were confirmed in non-African countries (e.g., USA, India, Taiwan), but the current evidence came from an African country. The result implies that programmes that can enhance residents' CCA may be associated with higher GPB, which encapsulates a spectrum of environment-friendly behaviours and etiquettes.

GPB was found to have a positive effect on biking but a negative effect on walking. This result suggests that individuals with higher GPB reported more biking time but less walking time. This counterintuitive result from the walking model was possibly explained by the consumption-oriented nature of GPB. Scales used to measure GPB, including the one used in this study, measure the consumption of products and services requiring travel to service delivery channels (e.g., malls, parks, and garages). In a city where these channels may be located far away from residents, higher GPB would be associated with less walking because residents with higher GPB would choose faster transportation types (e.g., biking or driving) over walking. Moreover, a negative effect of GPB on walking can be expected in sprawling cities such as Accra where service providers (e.g., malls, supermarkets, churches, and gyms) are located far from residential facilities (Asiamah et al., (2023b); Bempong & Asiamah, 2022).

The foregoing result constitutes the first empirical evidence on the link between GPB and walking as well as biking, though researchers (Asiamah et al., (2023a); Li et al., 2019) have conceded that socially responsible consumption behaviours such as GPB can encourage walking and biking. Some other researchers (Danquah et al., 2022; Opuni et al., 2022) drew on cross-sectional data collected in Ghana to reason that people who perform environment-friendly behaviours such as GPB are more likely to choose active forms of transportation (i.e., walking and biking), but the negative effect of GPB on walking time suggests that this may not always be the case in a city. Whether residents in a city would choose biking or walking over driving would depend on the suitability of weather conditions (Arnall, 2021; Bundy et al., 2023). Residents with a high GPB who routinely walk and bike for transportation may be compelled by heatwaves in a city to choose driving over walking and biking. Cities are known to be hotter than villages and smaller towns owing to industrial activities in them (López-Bueno et al., 2021; Ramamurthy & Bou-Zeid, 2017), so GPB would not always predict walking and biking in cities, especially in an African city where high temperatures may be extreme. Because cities are usually large, their destinations (e.g., shops and workplaces) may not be within walking and biking distances. So, individuals who want to walk may choose faster transportation options (e.g., driving) over walking and biking to save time. If so, residents who prefer to walk or bike owing to their GPB may be compelled to travel by a car.

We found a partial mediation of GPB in the effect of CCA on walking



SK – sustainability knowingness

Fig. 4. Effect of climate change awareness on green purchase behaviour at low and high sustainability knowingness (low = 415, high = 415; total = 830).

and biking. This mediation effect is partial because CCA can directly influence walking and biking without using GPB as a channel of influence. Noteworthy is the negative mediation by GPB in the walking model, which originates from the negative effect of GPB on walking. In a sprawling or relatively large city where people with high GPB and SK cannot walk to far places, a negative partial mediation in the walking model is more likely. If so, programmes to enhance environmental knowledge among residents may not necessarily encourage walking, which is problematic since walking is the most environment-friendly transportation type (Asiamah et al., (2023a); Frank et al., 2010; Rothman et al., 2018). For this reason, the design of compact neighbourhoods where service delivery channels are within walking distance is necessary. This effort would complement public education programmes aimed at enhancing environmental knowledge and its desired effect on walking and other types of active transportation in large cities.

SK moderated the effect of CCA on GPB in the sense that the positive effect of CCA on GPB was stronger at higher SK. Hence, our study supports the fifth set of hypotheses (H5a and H5b). This interaction effect possibly stemmed from the positive correlation confirmed between SK and pro-environmental behaviours in previous studies (Danquah et al., 2022; Opuni et al., 2022). To recall, the TIMSI and knowledge deficit model posit that higher environmental knowledge can be associated with higher pro-environmental behaviours. The above interaction builds upon this view as it signifies that two indicators of environmental knowledge can interact to influence pro-environmental behaviour. To advance the current research and demonstrate the consistency of our evidence, future studies may investigate three-way interactions (i.e., the interaction of three environmental knowledge indicators) on pro-environmental behaviours.

There was a moderated mediation in both models, but the moderated mediation effect on walking is negative owing to the negative effect of GPB on walking. This result signifies that the positive indirect effects of CCA on biking are stronger at different (higher) levels of SK. Conversely, the negative indirect effect of CCA on walking is stronger at higher levels of SK. As explained earlier, this counterintuitive result may be due to people walking less at higher SK and GPB because their destinations in the city are not reachable through walking. Researchers (Hofer-Fischanger et al., 2020; Oliver et al., 2014) have acknowledged that people would not walk for transportation if their destinations are not within walking distance, which is often the span of a neighbourhood or 10–15 min' walk from home (Sallis et al., 2010). The confirmed moderated mediation builds on the TIMSI and Knowledge Deficit Model by extending the individual and joint effects of CCA and SK on GPB to biking and walking. Both models originally acknowledged the individual effect of environmental knowledge on pro-environmental behaviour.

Our evidence has some implications for practice. Firstly, CCA and SK, if enhanced through relevant educational programmes, can encourage GPB and other pro-environmental behaviours. As reported in the literature (Estrada et al., 2017; Iturriza et al., 2020), incorporation of climate and environmental education in curricula, CCA creation through the mass media, and environmental activism by groups and individuals are ways by which the above environmental knowledge indicators can be improved. Future research should provide an understanding of why GPB may have a negative effect on walking. To this end, future studies may investigate the effect of "distance to destination" (i.e., the distance between homes and common destinations) on the association between GPB and walking. This relationship can be tested with a mediated moderation model in which "distance to destination" is treated as a moderator of the effect of GPB on walking. GPB is a potential mediator of the effect of CCA on walking in this model, so it can provide an understanding of whether people with high GPB linked to CCA report less walking but more biking or driving due to longer distances to destinations. This suggestion recalls a need for future studies to test and compare three mediated moderation models with walking, biking, and driving as dependent variables.

5.1. *Limitations and strengths*

Our cross-sectional design was unable to establish causation between the variables, so decision-makers and researchers should view the effect sizes as associations. Future researchers are encouraged to employ designs (e.g., experimental designs) that can establish causation if possible. We utilised a non-probability sampling method because we did not have a sampling frame. Further to this, the sample was taken from only Accra, so our findings may have limited generalizability. Although we aimed to recruit participants from all age groups, only adults aged 19–48 years agreed to participate in this study, which can further limit the generalizability of our evidence. The study was vulnerable to response bias because we utilised subjective measures (i.e., self-reported scales). Our procedures, nevertheless, confirmed the absence of common methods bias in the data. Future studies may employ objective measures in contexts where these measures can be used. For example, walking can be measured with activity trackers such as an accelerometer as a previous study (Kononova et al., 2019) demonstrated.

This study was the first to test an empirical model linking environmental knowledge indicators and pro-environmental behaviour (GPB) to walking and biking time. Thus, this study fills an important gap in the health-sustainability debate, given that walking and biking provide health benefits with no or negligible adverse impacts on the environment (Asiamah et al., (2023a)). Future researchers can add to this contribution by incorporating a measure of health (e.g., quality of life) in our moderated mediation models in their effort to investigate whether walking and biking positively influence health. By designing this study to meet STROBE criteria (see Appendix D for this checklist), we maximised its quality and usefulness to practitioners (Cuschieri, 2019). Another key strength was our sensitivity analysis for confounding with which we ensured that unnecessary variables were incorporated in our models as covariates. This sensitivity analysis was motivated by the assumption that confounding is not always possible and that only variables likely to confound the relationships of interest should be considered as covariates (Asiamah et al., 2021; Sghaier et al., 2022).

6. Conclusion

Individuals with higher CCA are more likely to perform GPB, bike, and walk. Higher GPB is associated with higher biking but lower walking time. CCA has an indirect positive effect (through GPB) on biking time but a negative indirect effect on walking time. At higher levels of SK, CCA more strongly predicts GPB. The indirect positive effect of CCA on biking is stronger at higher SK. Conversely, the negative indirect effect of CCA on walking time is stronger at higher SK. Health education and social marketing programmes aimed at improving both CCA and SK may encourage biking for transportation in a city. GPB may not result in walking in large cities where common destinations may not be reached with walking.

CRediT authorship contribution statement

Nestor Asiamah: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Frank Frimpong Opuni:** Writing – review & editing, Validation, Supervision, Project administration, Conceptualization. **Isaac Aidoo:** Writing – review & editing, Visualization, Data curation, Conceptualization. **Nana Benyi Ansah:** Writing – review & editing, Validation, Data curation, Conceptualization. **Toku Lomatey:** Writing – review & editing, Validation, Data curation, Conceptualization. **Faith Muhonja:** Writing – review & editing, Validation, Data curation, Conceptualization. **Kafui Agormeda-Tetteh:** Writing – review & editing, Validation, Conceptualization. **Prince Koranteng Kumi:** Writing – review & editing, Validation. **Eric Eku:** Writing – review & editing, Validation, Conceptualization. **Musa**

Osumanu Doumbia: Writing – review & editing, Validation, Conceptualization. **Theophilus Kofi Anyanful:** Writing – review & editing, Visualization, Conceptualization.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2024.101134.

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