Highlights

- Right mixes of urban green-blue spaces could promote different physical exercises.
- More walked in areas higher in both forest and scrub cover.
- Walking frequency increased with managed vegetation cover.
- Team-sports uptake and frequency grew with managed open-canopy vegetation cover.
- Individual exercise frequency rose with higher water-and-open-greenery and forest-and managed-treescape cover.

Abstract

Growing recognition of nature's benefits to many aspects of human wellbeing has prompted the incorporation of both urban green and blue natural outdoor environments (NOEs) into cities. Amongst the many purposes of NOEs, promotion of physical exercise has been garnering interest, given the increasingly sedentary lifestyles of urban dwellers. However, studies rarely consider how different types of NOEs, let alone the combination of them, might affect the type and frequency of physical exercise conducted by urban residents. We use Singapore, a highly urbanised tropical nation with a considerable number of NOEs, as a case-study to address these gaps. We used a market research survey (n = 1,519), geographic information systems, and generalised linear regression models to investigate the relationship between residential NOE cover, exercise-influencing sociodemographic factors, and outdoor exercise choice (i.e., if respondents exercised or not) and frequency of four types of physical exercises: walking, individual-based, team-sports, and overall exercise. For exercise choice, more people walked in areas with higher forest and scrub cover, and less in areas with just scrub. Less conducted individual-based exercise in areas with high unmanaged vegetation cover, and more conducted team-sports in areas with higher open-canopy managed vegetation cover. Amongst those who engaged in these exercises, managed vegetation cover is positively correlated with walking (open- and closed-canopy combined) and team-sports (open-canopy) frequency. Individual-based exercise frequency rose in areas with a mix of high open-canopy managed vegetation and blue space cover within 250 m from one's home, and a mix of high managed treescape and forest cover 500 m from one's home. Findings suggest that a specific mix of NOEs can promote the participation of different types of physical exercise. Integrating the right NOE types and combinations into urban residential spaces may thus help to mitigate sedentary lifestyles, boosting public health outcomes in city populations.

Keywords: City design and planning; Forested parks; Health; Managed wilderness; Scrubland-forest patches; Urban green-blue spaces

1. Introduction

Physical inactivity, defined as conducting less than 150 minutes of moderate- to vigorous-intensity physical activity per week (Piercy et al., 2018), is a global public health concern (Booth and Laye, 2012; Guthold et al., 2018; Wagner and Brath, 2012). It is not only the fourth leading risk factor contributing to premature mortality worldwide (World Health Organization, 2010), but can also trigger and/or aggravate the severity of other risk factors such as high blood pressure and cholesterol (Booth and Laye, 2012; Durstine et al., 2013). Physical inactivity can also compound the negative effects of pre-existing chronic diseases such as cardiovascular disease, cancer, diabetes, and respiratory disorders, which themselves are increasingly accounting for a majority of global mortality (Strong et al., 2005; Wagner and Brath, 2012). This phenomenon is set to rise since the proportion of the world's population living in cities, where sedentary lifestyles are especially prominent (Guthold et al., 2018), is growing at a rapid rate (Kohl et al., 2012; Wagner and Brath, 2012). Given the high healthcare and productivity costs that arise from physical inactivity (Ding et al., 2016), there is an urgent search for mitigation measures to alleviate this global healthcare issue.

Amongst the many possible solutions to reverse sedentary lifestyles, the integration of nature into public spaces to promote physical exercise has attracted much interest. Physical exercise refers to the structured, repetitive and planned movements aimed at maintaining or improving physical fitness (American College of Sports Medicine, 2013). Exercising is well-known to bring a slew of physical, mental, and cognitive health benefits (Booth et al., 2012; Penedo and Dahn, 2005; Ploughman, 2008). Similarly, exposure to nature is increasingly found to generate a multitude of direct health benefits (Cox et al., 2017; Keniger et al., 2013; Kuo, 2015), such as by strengthening immunity and alleviating various mental disorder symptoms (Berman et al., 2008; Fan et al., 2011; Kuo, 2015). It also confers indirect health benefits, such as acting as a platform for mental restoration (Berman et al., 2008; Hartig et al., 2003), and for strengthening social ties (Fan et al., 2011; Maas et al., 2009; Seeland et al., 2009).

Combining physical exercise with nature exposure in cities could yield concomitant positive health benefits (Rogerson et al., 2016; Shanahan et al., 2016; Yang et al., 2019). Physical exercise in natural outdoor environments (NOEs), defined as urban green and blue spaces, both open and closed canopy managed and unmanaged, may enhance health benefits.

Mechanisms through which this might occur are varied, for example, the presence of nature and/or fresh air in NOEs could make exercising more enjoyable and restorative (Karusisi et al., 2012; Lahart et al., 2019; Rogerson et al., 2016). This can improve short-term mental health indicators such as mental restoration (Barton and Pretty, 2010; Rogerson et al., 2016) and increase one's motivation to exercise (Hagberg et al., 2009; Schwaneberg et al., 2017). In some instances, NOEs are spaces to conduct easy-to-adopt (e.g., jogging) and group exercises (e.g., team sports), facilitating the incorporation of physical activity into one's lifestyles (e.g., Rogerson et al., 2016; Sugiyama et al., 2013).

However, much of the research on the effects of NOEs on physical exercise has been constrained to the cooler and seasonal temperate regions (e.g., Schipperijn et al., 2017; Shanahan et al., 2016; Toftager et al., 2011), which could differ from the year-round humid and warm tropics, where much of the world's urbanisation is occurring (McDonald et al., 2013). Different physical exercise types may also have different relationships with NOEs due to their different characteristics, such as the physical intensity (e.g., running versus walking; Rogerson et al., 2016), and level of social interaction involved (e.g., team-sports versus running; Mytton et al., 2012). Knowledge gleaned from addressing these gaps could better guide urban green-blue space planning and design to improve health and wellbeing.

Furthermore, the type of green and/or blue spaces within NOEs available might strongly influence the prevalence and type of physical exercise (e.g., Akpinar et al., 2016), yet this issue has received relatively little attention. Natural outdoor environments are diverse, ranging from less-managed and sometimes non-delineated urban forest patches and spontaneous scrubland, highly manicured grass turfs and roadside trees, to those with a mix of blue and green spaces (e.g., waterfront parks) or various types of vegetation (e.g., parks with both forest and managed vegetation). Much research, however, tend to either focus on a subset of NOEs such as urban forests, or generalise different types of NOEs under a broad place-based category such as parks (e.g., Martens et al., 2011; Vaeztavakoli et al., 2018). The effects of having multiple green spaces, and/or green and blue spaces in a NOE receives even less attention, with comparative studies between different types of NOEs being more popular (e.g., Hansmann et al., 2007; Nutsford et al., 2016). This is despite NOEs often having multiple green and blue spaces. Understanding how green and blue spaces within NOEs could have differential effects on one's choice and frequency of physical exercise can thus be utilised to refine public NOEs to enhance physical activity.

Singapore can serve as a good case study to address these gaps. The country is a tropical highly urbanised city, with only 0.2% of original unmanaged natural vegetation remaining (Corlett, 1992). Yet, NOEs are distributed relatively evenly across 54.6% of its surface, and range from forests, manicured parks of varying tree cover, to waterfronts and spontaneous scrubland (Gaw et al., 2019). These NOEs can be where Singaporeans conduct their various physical exercises, from moderately intense exercises such as brisk-walking, to more intense individual-based exercises such as jogging, to team-sports exercises (Sports Singapore, 2016). However, the frequency of exercise is still a concern in Singapore, one of the most sedentary populations in the world (Guthold et al., 2018), necessitating urgent attention.

We thus investigated the association between outdoor physical exercise choice and frequency and NOEs near one's homes, since the proximity of NOEs to homes has been widely recognised to be a contributing factor to the tendency to conduct physical exercise in many non-tropical cities (Browning and Lee, 2017; Sturm and Cohen, 2014). Specifically, we 1) determined whether there is an association between outdoor physical exercise and percentage cover of various NOEs types; 2) assessed whether outdoor physical exercise increases with proximity of residential NOEs cover; and 3) investigated whether different types of NOEs were associated with different types of outdoor physical exercise, namely, walking, individual-based exercises, team-sports exercises, and overall exercise.

2. Methods

2.1. Data collection

An online questionnaire was delivered by an external market research company to 1,519 adult (≥ 18 years old) Singaporeans and Permanent Residents from 14th January to 14th February 2019. The entire survey had 49 questions and was designed to understand how urban green and blue spaces influence residents' lifestyles and well-being in Singapore, 22 of which are relevant to this study. These questions were adapted and built upon a similar 2012 survey conducted in Australia (Lin et al., 2017; Shanahan et al., 2016).

Respondents were recruited by the market research company through their existing survey respondent database. Respondents were stratified to reflect the demographic composition (age, gender, income quartile, and ethnicity; Singapore Department of Statistics, 2018) and the geographic distribution of residences (i.e., administrative housing units) were spread across the four quartiles of greenspace coverage across residential areas. To estimate

residential NOEs availability, we collected respondents' house postal codes, which provides geographical information of the private residential house or residential housing block. Six respondents provided the postal code of the block or nearest street to their dwelling as they chose not to reveal their postal codes. The postal codes were then used to calculate the NOE cover around the respondents' place of residence. This was then mapped using the Google API service via the R package, ggmap (Kahle and Wickham, 2013), and subsequently overlaid with an updated map of Singapore's terrestrial (including vegetation, freshwater and urban) ecosystems (Gaw et al., 2019), resampled from a grid size of 30 cm to one of 3 m for computational feasibility. By utilising remotely sensed classified types of vegetation rather than officially designated NOEs (e.g., parks), we include NOEs that are not administratively delineated. This includes unmanaged green spaces such as small scrublands and forest patches that are embedded within the urban matrix, which are more accessible unmanaged NOEs for some residents compared to the Central-located forested reserves (see "waste-woodlands" in Yee et al., 2016). The use of blue-green space cover also allowed for finer resolution of locations with managed NOEs. This includes parks, which can have different dominant vegetation types (e.g., more open versus closed-canopy, terrestrial versus coastal/reservoir parks), thereby giving us a better understanding of what NOEs may be associated with specific exercise types.

To investigate the relationship between NOE proximity and outdoor physical exercise, the amount of residential NOE cover within 250 m, 500 m, 1 km, and 1.5 km radial buffers around each respondent's dwelling was extracted. These buffer sizes were informed by previous studies showing that these are the distances that people might travel to exercise (Halonen et al., 2015; Higgs et al., 2015) and/or to visit parks to conduct physical activity (Kaczynski et al., 2014; Schipperijn et al., 2017). They also correspond to Singapore's green space targets: the 250 m distance buffer corresponds to the minimum recommended distance between the furthest residence along a public pedestrian walkway to the nearest public NOE according to the guidelines on greenery provision for Singapore's developments (National Parks Board, 2018). The 500 m and 1 km distance buffers correspond to the country's statutory land use plan's approximate target of bringing 90% of the population's home within a 10-minute walk to the nearest park (Urban Redevelopment Authority, 2019). The 1.5 km distance buffer corresponds to the maximum buffer distance at which all NOE cover around respondents' residences can be calculated without extending beyond the boundary of Singapore. Urban green spaces were classified into the following types: 1) unmanaged open-

canopy vegetation (i.e., “vegetation with limited human management without tree canopy” and “freshwater marsh” in Gaw et al. (2019)); 2) unmanaged closed-canopy forest (i.e., “vegetation with limited human management with tree canopy”, “mangrove”, and “freshwater swamp forest”); 3) managed open-canopy vegetation (such as shrub plots and grass turfs; “vegetation with structure dominated by human management with tree canopy”); 4) managed close-canopy vegetation (such as planted treescape); 5) blue space (merged “marine”, “water courses” and “water bodies”; as marine bodies were absent in 83–99% of respondents’ residences). In addition, these categories were also combined to explore the effects of more general green space NOEs on exercise. These included 6) trees (a combination of category 2 and 4; to explore the effect of general tree canopies on exercise); 7) shrubs (a combination of category 1 and 2; to explore the effect of general open-canopy vegetation on exercise); 8) unmanaged (a combination of category 1 and 2); and 9) managed (a combination of category 3 and 4). The NOEs were expressed as a proportion of the total buffer area.

Sociodemographic information was collected for variables that have been shown to influence physical exercise habits in Singaporeans. These included age (Uijtdewilligen et al., 2017; Win et al., 2015), gender (Guthold et al., 2018; Uijtdewilligen et al., 2017; Win et al., 2015), highest educational qualification (Uijtdewilligen et al., 2017; Win et al., 2015), ethnicity (Sumner et al., 2018; Uijtdewilligen et al., 2017), housing type (Sport Singapore, 2016), individual income/allowance, and occupational status (Win et al., 2015; Sports Singapore, 2016) (Fig. 1). Education was a categorical variable consisting of Singapore’s multiple educational pathways: postgraduate degree, bachelors’ degree, pre-university certification (an academic education that culminates to a GCE A-Level certification), polytechnic diploma (a post-secondary practice-based vocational education in polytechnics), Institute of Technical Education (ITE) diploma (a three-year post-secondary technical vocational training education in ITE), secondary certification (a four to five-year academic education culminating to GCE O or N-Levels examinations), or either a primary or no formal education. Housing was a categorical variable that encompasses Singapore’s different housing types, from the various government-subsided public housing (where 78.6% of Singaporeans reside in; Singapore Department of Statistics, 2018) to the more expensive private housing (condominiums, and landed housing).

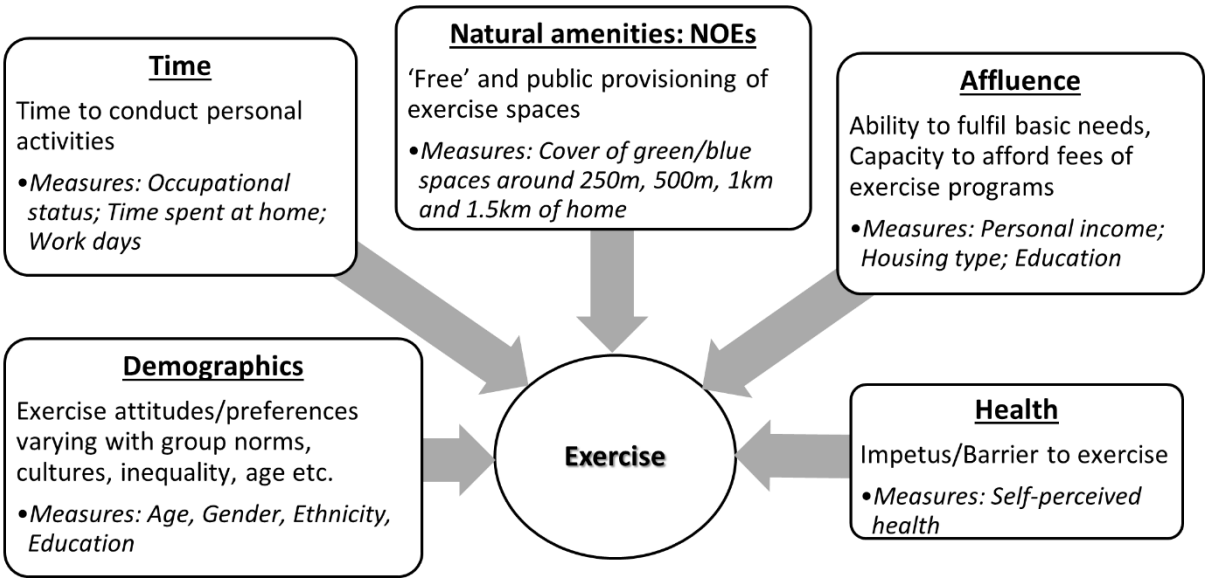

Fig. 1.: Illustrated summary of factors hypothesised to affect physical exercise.

As the lack of time has been reported to be the greatest hindrance to conducting physical exercise in Singapore (Sport Singapore, 2016), the estimated number of hours spent at home in a week were also collected. Occupational status was used as a proxy for the amount of non-work time a person might have available, something that has been shown to affect sports participation (Sport Singapore, 2016). It included the following categories: working full-time, working part-time, unemployed, homemaker (person whose principal role is to manage household chores), student, and retiree at the time of the survey. In addition, perceived health scores (based on a Likert scale from 1–5) were collected, given that perceived health is often a factor that influences exercising habits (Sport Singapore, 2016).

We requested information on self-reported number of outdoor physical exercise sessions done over the past week, as this recent time frame within the survey period would minimise recollection bias (Schwarz and Oyserman, 2001). Physical exercise was defined as any type of structured/routinised physical activity that caused one to breathe heavily, puff, and/or pant. This formed two response variables: exercise choice and exercise frequency. Exercise choice is a binary variable of whether respondents conducted the following types of physical exercise: 1) walking (for ≥ 30 minutes per session), 2) individual-based moderate-to-vigorous intensity exercises (e.g., running/jogging and swimming), 3) team-sports exercises (e.g., soccer, badminton, and basketball), and 4) overall exercise (combination of the three physical exercise types) over the week before they took the questionnaire. These categories follow the Sport Singapore's (2016) Sports Index survey. A separate category, "others" (defined as moderately to vigorous physical activity such as gardening and physically-intensive chores

such as moving heavy objects), was included to ensure that respondents would not mistake other physical activities for physical exercise. This was excluded from the analysis. Exercise frequency refers to the number of times exercising respondents conducted each type of physical exercise over the past week.

This study was conducted in accordance with the Institutional Review Board at the National University of Singapore (IRB reference code S-18-344) and University of Queensland Institutional Human Research Ethics Approval (project number 2018001775). All respondents were above 17 years old and voluntarily participated in the survey by providing informed consent to participate.

2.2. Statistical analyses

All statistical analyses were conducted in the R statistical environment (R Core Team, 2019). The correlation between NOE cover and sociodemographic variables with exercise choice was analysed with generalised linear regression models (GLMs) with binomial error distribution. The correlation between NOE cover and sociodemographic variables with exercise frequency (a count of how many times one exercises over the past week) of exercising individuals (i.e., only those who engaged in the exercise of analysis) was analysed with GLMs with either negative binomial or Poisson error distribution. Values were scaled (deduct mean and then divide by standard deviation) for all continuous variables for analyses.

To prevent collinearity (generalised variance inflation factor score < 3) among measures of NOEs, variables from different buffer sizes were never included in the same model (Supplementary information). Within each buffer size, all NOEs types were not collinear. A suite of models was proposed, ranging from a full and a null model, models with only all NOEs types (within a buffer) and only all sociodemographic variables, hypothesised models based on previous studies on sociodemographic factors affecting Singaporean exercise choice (Guthold et al., 2018; Sport Singapore, 2016; Win et al., 2015) and exercise frequency (Sport Singapore, 2016; Sumner et al., 2018; Uijtdewilligen et al., 2017) habits, and hypothesised models with sociodemographic factors and possible interactions between different NOEs variables, based on the presence of such combinations in Singapore's landscape (Gaw et al., 2019). The list of proposed models is found in the Supplementary information. The models were then compared using the Akaike information criterion for small sample sizes (AICc) to select the best-performing model for results interpretation. An averaged model was used for individual-based exercise frequency, as all the models were not strongly weighted (i.e.,

weight < 0.3 (Symonds and Moussalli, 2011)). Model averaging involved the averaging of the coefficients and standard errors for each explanatory variable of candidate models with ΔAICc < 2 (Anderson and Burnham, 2002; Symonds and Moussalli, 2011) that are less complex than the best-performing model (Richards, 2008) and are non-collinear when combined with the best-performing model (Cade, 2015). We used the package "visreg" (Breheny and Burchett, 2017) to visualise interactions between variables.

3. Results

3.1. Overall exercise patterns

Respondents reflected the Singaporean demographic distribution (Supplementary information). Of the 1519 of them, 48 were excluded from the analysis due to missing and/or incorrectly filled data. 1039 respondents exercised at least once a week prior to the survey period. Of these, 90.6% exercise outdoors, 73.1% walked in ≥ 30-minute sessions, 46.3% conducted individual-based exercises, and 12.2% engaged in team-sports exercises. Amongst those who exercised, the mean number of outdoor exercise sessions conducted over the past week was highest for walking (3.56 times ± 0.093 SE), followed by individual-based exercises (3.03 times ± 0.094 SE), and lastly, team-sports exercises (2.27 times ± 0.157 SE). Physical exercises were not mutually exclusive.

3.2. Exercise choice

All exercise types have natural outdoor environment (NOE) variable/s included in their respective best models (Fig. 2). For overall exercise, there was an interaction between tree (includes forest and managed treescapes as a whole) and blue space cover ("1K_water" in Fig. 2A and 3A) within 1 km from one's home: In areas with low tree cover, more people conducted exercise in spaces with greater blue space cover, but the opposite was true when tree cover is high. Open-canopy managed vegetation cover within close proximity of a home (i.e., 250 m) was positively correlated with team-sports exercise ("250_Mshrub" in Fig. 2B). Unmanaged vegetation cover was negatively correlated with individual-based exercise ("1.5K_unm" in Fig. 2C) at a greater buffer size of 1.5 km from a residence. For walking exercise, there was an interaction between forest and unmanaged open-canopy scrubland within 1.5 km of a residence (Figs. 2D and 3B; where "1.5K_Utree" is forest, "1.5K_Uscrub" is scrubland). Less people walked in areas with scrubland where forest cover is low ≤ 4% but increased where forest takes up ≥ 20.5% of the residential buffer space (Fig. 3B).

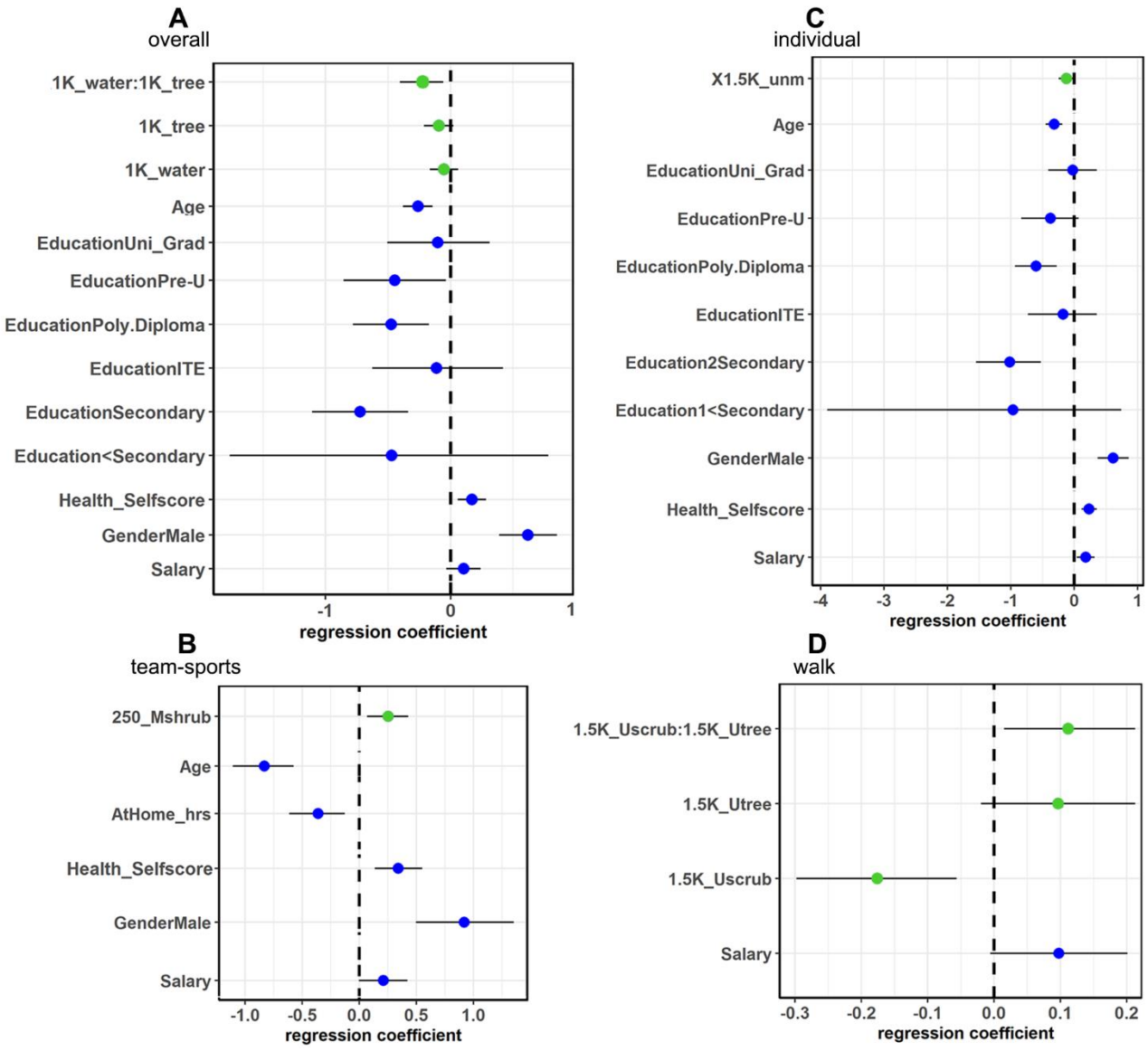

Fig. 2.: Effect sizes (scaled log odds) with 95% confidence intervals of best-performing exercise choice models for: A) Overall exercise; B) Team-sports exercise; C) Individual-based exercise; D) Walking. All green points refer to a NOE variable, where the number before "_" refers to the buffer size (250: 250 m, 500: 500 m, 1K: 1 km, 1.5K: 1.5 km). tree = Both tree-dominated closed-canopy forests and managed treescapes; water = all blue spaces (e.g., Reservoirs, canalised rivers, streams, marine waters); Uscrub = Unmanaged open-canopy habitat (e.g., scrubland); Utree= Unmanaged tree-dominated closed-canopy forests; unm = unmanaged vegetation (both open-canopy and closed-canopy); Mshrub = Managed open-canopy habitats (e.g., shrub plots, grass turfs). Education: Highest education qualification being Uni_Grad: postgraduate degree; Uni = bachelors' degree; Pre-U = pre-university certification; Poly.Diploma = polytechnic diploma; ITE = Institute of Technical Education diploma, Secondary = secondary school GCE O or N-Level certification; <Secondary = Primary school and no formal education. All variables in the model are presented.

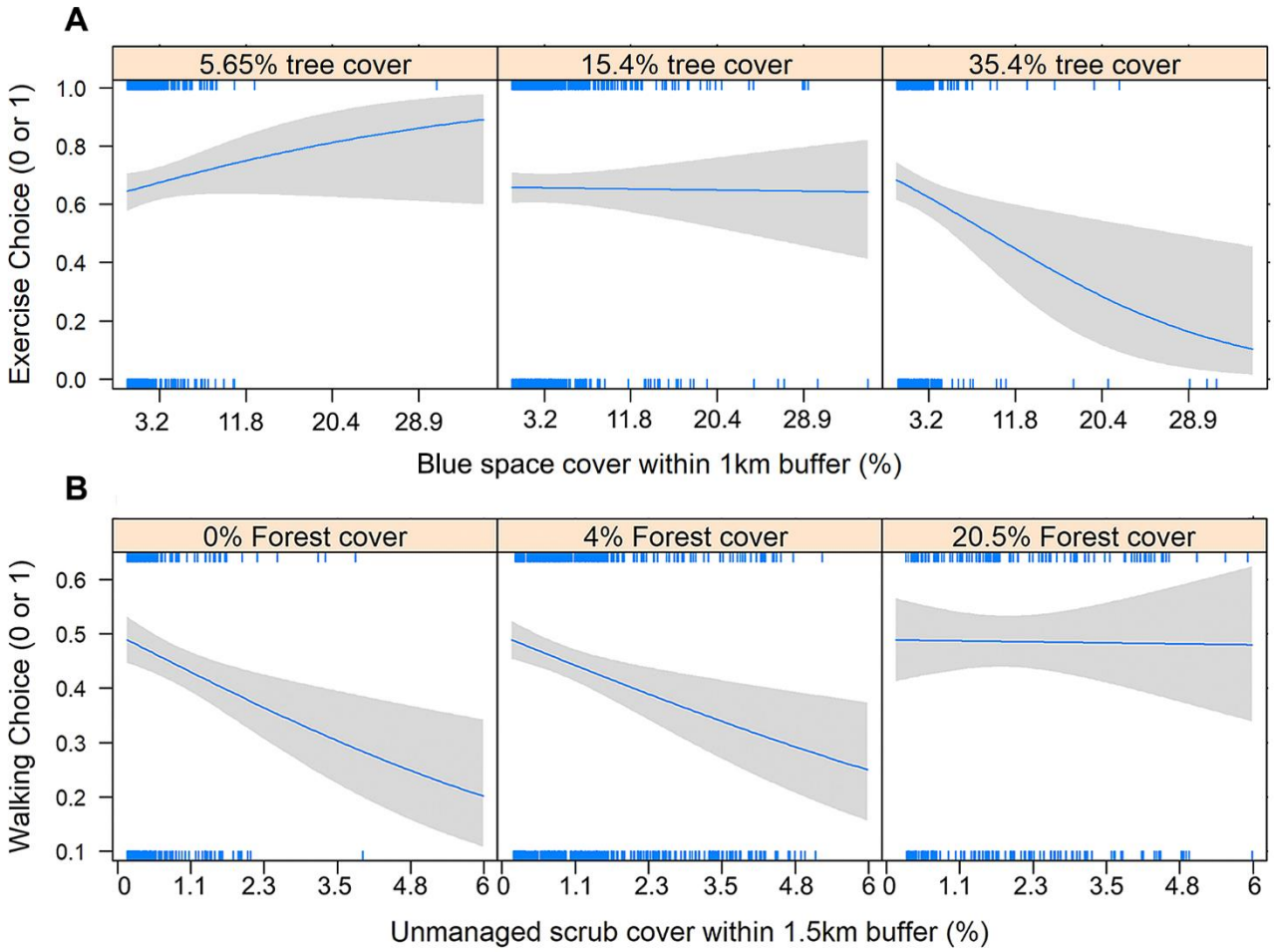

Fig. 3.: Two-way interaction plots illustrating the interaction effect of tree (both forest and managed treescapes) and blue space cover within 1 km of a respondent's residential area on the tendency to conduct **A**) Overall exercise; and interaction effect of Forest and Unmanaged scrub cover within 1.5 km of an individual's residential area on the tendency to conduct **B**) Walking exercise. Shaded area refers to 95% confidence intervals. x-axis values displayed are the 10th, 50th, and 90th percentiles, and are back transformed from scaled log odds units.

Individuals who exercised tend to be male, younger, have a higher perceived health and greater personal salary (slightly for overall exercise and walking; Fig. 2). On top of these, individuals who conducted individual-based and overall exercise were characterised by having lower educational qualifications (i.e., either secondary education or polytechnic diploma; Figs. 2A and C), while those who engaged in team-sports exercise usually spend less time at home (Fig. 2B).

3.3. Exercise frequency

Similar to exercise choice, all the best and averaged exercise frequency models included NOE variables. Overall exercise frequency increased with open-canopy managed vegetation (i.e., managed shrub and/or grass turfs) within 1.5 km from one's home and less in areas with

higher levels of blue space cover within 1.5 km from one's home ("1.5K_Mshrub" and "1.5K_water" respectively in Fig. 4A).

Similar to team-sports choice, team-sports frequency increased with managed open-canopy vegetation (i.e., grass turfs, shrubs) within 250 m of one's home (Fig. 4B). Managed vegetation cover (both open- and closed-canopy) within 500 m of a residence was positively correlated with walking frequency ("500_man" in Fig. 4C).

For individual-based exercise, there was an interaction between blue space and managed open-canopy greenspaces within 250 m from a residence. At low open-canopy vegetation cover $\leq$ 5.6 %, the number of individual-based exercises conducted per week decreased with blue space cover. However, when open-canopy vegetation cover is high $\geq$ 24.1 %, individual-based exercise frequency increased with blue space cover (Figs. 4D and 5A). At 500 m, the NOE interaction that is correlated to individual-based exercise frequency changes to one between unmanaged close-canopy vegetation (i.e., forest) and managed close-canopy vegetation (i.e., managed treescapes). In areas with low managed tree cover $\leq$ 3.5 %, frequency decreased with higher levels of forest cover. But when areas have managed tree cover $\geq$ 23 %, individual-based exercise frequency increased with forest cover (Fig. 5B).

The best exercise frequency models included gender (except for walking), higher perceived health (except team-sports), and a positive quadratic salary function (except individual-based exercise; Fig. 4). For overall (Fig. 4C) and individual-based exercise (Fig. 4D), Singaporean Indians (and Malays for individual-based exercise) exercised more frequently than Chinese. Individual-based exercise frequency was also higher in homemakers with higher perceived health relative to full-time workers (Fig. 4D).

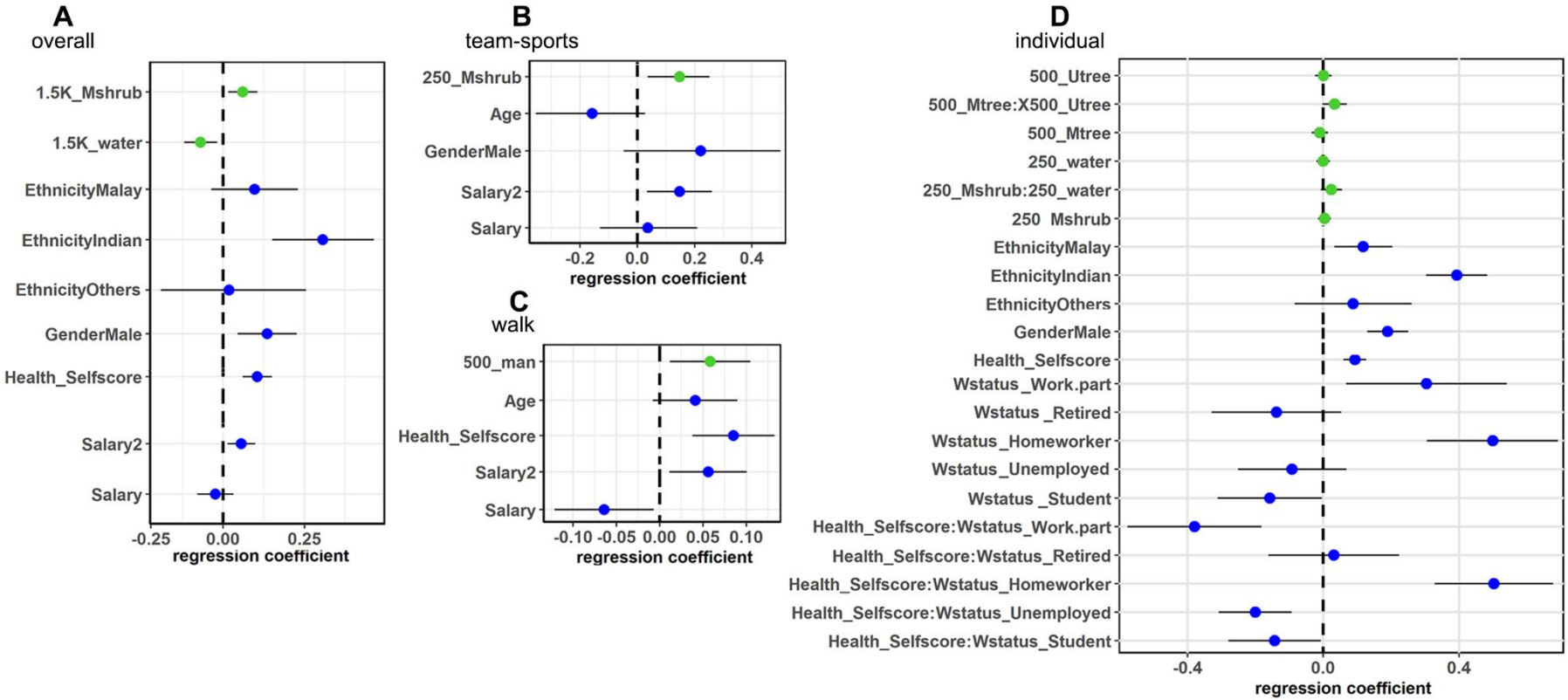

Fig. 4.: Effect sizes (scaled logs) with 95% confidence intervals of best-performing exercise frequency models for: **A)** Overall exercise; **B)** Team-sports exercise; **C)** Walking; **D)** Individual-based exercise amongst exercise practitioners. All green points refer to a NOE variable, where the number before "_" refers to the buffer size (250: 250 m, 500: 500 m, 1K: 1 km, 1.5K: 1.5 km). water = all blue spaces (e.g., Reservoirs, canalised rivers, streams, marine waters); Mshrub = Managed open-canopy habitats (e.g., planted shrub plots, grass turfs); Utree= Unmanaged tree-dominated closed-canopy forests; man = managed vegetation (both open-canopy and closed-canopy). Education: Uni_Grad: postgraduate degree; Uni = bachelors' degree; Pre-U = pre-university certification; Poly.Diploma = polytechnic diploma; ITE = Institute of Technical Education diploma, Secondary = secondary school GCE O or N-Level certification; <Secondary = Primary school and no formal education. Wstatus refers to working status. Salary2 refers to the quadratic salary function. All variables in the model are presented.

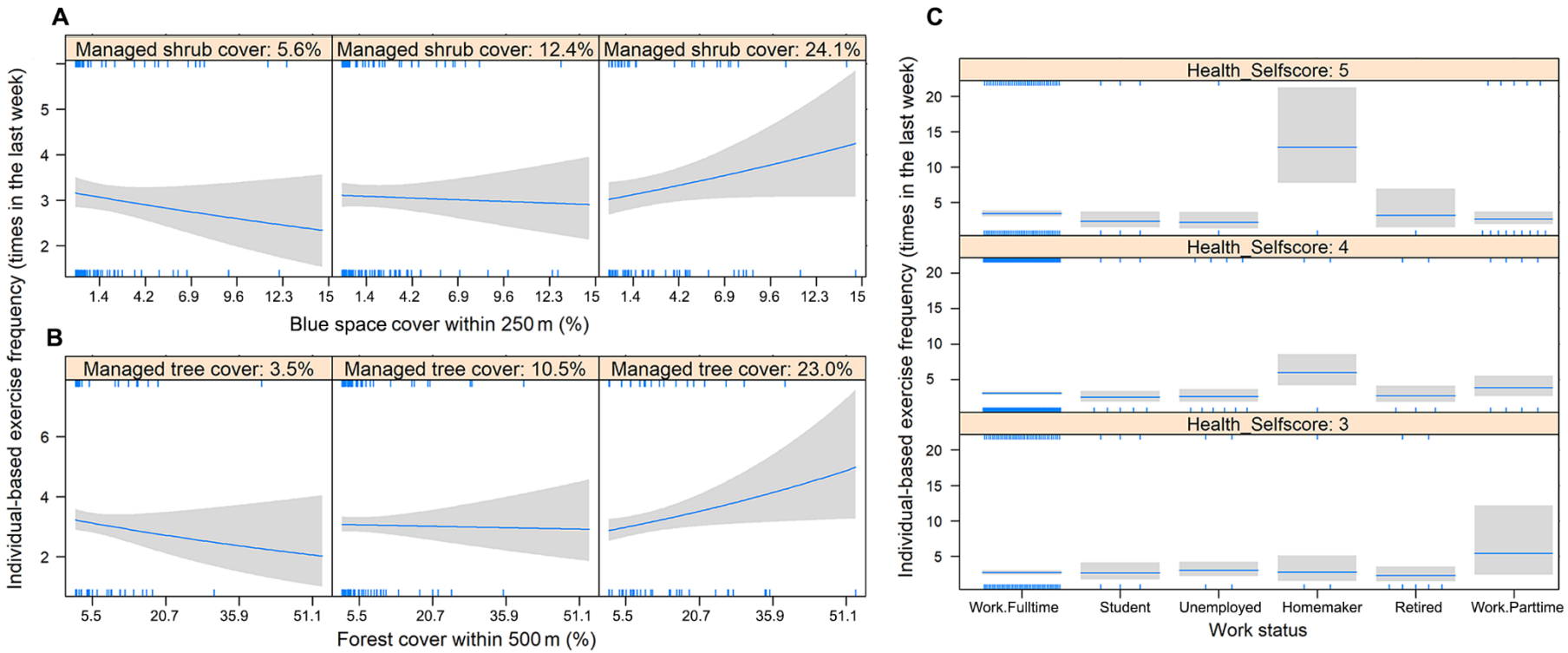

Fig. 5.: Two-way interaction plots illustrating the interaction effect of **A)** Forest and managed vegetation (i.e., closed-canopy treescapes and manicured open-canopy turfs and shrub plots) cover, within 1.5 km of one's home, on team-sports frequency of those who engage in the exercise; **B)** Water and managed open-canopy vegetation (i.e., manicured turfs and shrub plots) cover, within 250 m of one's home, on overall exercise frequency amongst exercise practitioners; **C)** Blue space and managed open-canopy vegetation cover, within 250 m of one's home, and **D)** Perceived health scores and work status, on individual-based exercise frequency amongst those who engage in individual exercises. Shaded area refers to 95% confidence intervals. x-axis values displayed are the 10th, 50th, and 90th percentiles, and are back transformed from scaled log units.

4. Discussion

4.1. Different physical exercise types are correlated with different NOE types

Natural outdoor environments (NOEs), be it urban green space and/or blue space cover, were included in the best models for choice and frequency of all the outdoor physical exercises investigated. Higher managed vegetation cover is one of the key features in NOEs that draws outdoor physical exercise, be it by itself or together with other types of green/blue spaces. For team-sports, the thicker and structurally more complex nature of unmanaged vegetation (Hoyle et al., 2019; Khew et al., 2014) could hinder such exercises. Team-sports exercises, such as frisbee and soccer (Sports Singapore, 2016), tend to require unhindered, turf-like open spaces when played outdoors. This could explain the strong positive correlation between team-sports exercise and open-canopy managed NOEs (Figs. 2B and 4B), which tend to be turfs, lawns, or manicured shrub plots between residences, in parks or golf courses.

For the other types of physical exercises, the negative correlation with unmanaged vegetation (Fig. 2C) and the corresponding positive correlation with managed vegetation (Figs. 4C and 4D) may also be due to perceived safety. This could be attributed to a combination of factors—the greater shade, structural complexity, reduced signs of human habitation and absence of possible escape routes can cause one to perceive these spaces as one that leaves one easily susceptible to crime and assault (Khew et al., 2014). In contrast, managed vegetation are comparatively neater and simpler in physical structure (Fan et al., 2011; Khew et al., 2014; Liu et al., 2016) with well-provisioned accessibility/safety infrastructure (e.g., lights, pathways). These elements of neatness and familiarity in managed NOEs gives a sense of higher perceived safety (Chiang et al., 2017; Jorgensen et al., 2007; Martens et al., 2011; Zhang et al., 2013), which may be especially pivotal for individual-based physical exercises (Figs. 2C and 4D). It could also be important in boosting exercise frequency (Hovell et al., 1989; Humpel et al., 2002), hence the positive correlation with walking frequency (correlated with managed open-canopy lawns/planted shrub plots and closed-canopy treescapes in general; Fig. 4C) and individual-based exercise frequency (correlated with open-canopy waterways and forested parks; Figs. 4D, 5A and 5B).

A possible exception would be the scrubland-and-forest patches in Singapore, which were found to attract more individuals to conduct walking exercises (Fig. 2D). These areas tend to be sparsely located in the heartlands as small, highly-fragmented degraded secondary forest patches near some residences (Gaw et al., 2019; Yee et al., 2016), breaking up the outline of a typical urbanised housing landscape. Thus, while structurally complex and dense, the

presence of residential areas near these small unmanaged forest-scrub patches (Gaw et al., 2019) help increase familiarity and thus reduce fear of these habitats (Khew et al., 2014). The contrasting setting of a less managed, non-concretised outdoor green space area could instead act as a space to dissociate, and thus direct one's attention away from routine demands, making them attractive to visit (Berman et al., 2008; Martens et al., 2011). Their lower ambient temperatures as compared to other urban spaces, including managed NOEs (Napoli et al., 2016; Richards et al., 2020), would further increase visitation, given how trees are especially favoured for their temperature-regulating benefits (Drillet et al., 2020). It remains uncertain whether the larger buffer size of 1.5 km for such unmanaged NOEs is driven by the scarcity of such NOEs amongst residential areas as compared to managed NOEs, the demand for cooling outdoor environments for walking exercises, or both. Nevertheless, this highlights that under specific circumstances (i.e., when the perceived dangers are eliminated and when in proximity to homes), small patches of less-managed wild vegetation may be attractive to walk in the highly urbanised residential area.

Our study reaffirms the increasing popularity of heterogenous NOEs with naturalistic appearances (Chiang et al., 2017; Hwang et al., 2019; Özgüner and Kendle, 2006). These NOEs are characterised by either having a mix of neat managed landscapes and wilder natural environments, and/or multiple types of green and/or blue spaces. Examples of NOEs with a combination of manicured landscapes and rarer natural habitats includes the small and thus more palatable wilderness within the urban matrix (i.e., the scrub-forest patches for walking choice; Figs. 2D and 3B), and areas with forests among well-maintained treescapes (e.g., forested parks for individual exercise frequency, Figs. 4D, 5A and 5B). The presence of varying vegetation heights, naturalness and/or habitats increases structural diversity/ heterogeneity (Chiang et al., 2017; Hoyle et al., 2019; Hwang et al., 2019; Özgüner and Kendle, 2006), enhancing their aesthetic and restorative value (Hoyle et al., 2017; Khew et al., 2014). Such forested NOEs also deliver the highly sought-after ecosystem service of cooling (Richards et al., 2020), boosting the likeability, and thus, visitation and usage of NOEs for physical activity (Deelen et al., 2017; Jansen et al., 2017).

Another naturalistic, heterogenous NOE that our study uncovered to be correlated with higher exercise frequency is one where managed open-canopy vegetation meets blue spaces (e.g., walkways with waterways beside them and waterfront parks for individual exercise frequency, Figs. 4D and 5A). Blue spaces are often seen as visually-attractive naturalistic features amongst green spaces, boosting the draw to conduct exercises such as jogging

(Barton and Pretty, 2010; Karusisi et al., 2012; Rogerson et al., 2016). The similarly open panoramic spaces of manicured shrub plots and/or turfs would complement, and thus enhance contemplative and/or self-restorative experiences that are usually elicited in waterscapes (Hipp and Ogunseitan, 2011; Völker et al., 2016). Furthermore, the neat, visible edges from shrub-scapes or waterways could offer moderate amounts of orientation and/or structure amidst the vastness, thereby giving a sense of managed naturalness that appeals to the masses (Hoyle et al., 2017; Völker et al., 2016). Both open blue-green NOEs and forested parks could serve the same role of satisfying one's inclination towards naturalistic landscapes, whichever is more readily available—open blue-green NOEs cover a slightly larger area than forested parks in the immediate proximity of one's home, and vice versa (Supplementary information). Hence, while managed NOEs are desired, this study suggests a more nuanced preference for greater NOE type diversity within these spaces, be it as a mix of unmanaged vegetation between familiar residential areas, a combination of forest and managed treescapes, or as a mix of green and blue spaces. Urban planners could thus consider the provision of a variety of semi-tended NOEs, offering waterway views at walking/jogging paths, and even leaving and providing minimal maintenance to some unmanaged vegetation plots (e.g., pruning of overgrown plants only) to promote physical exercise within the proximity of people's homes.

The effect of NOE proximity may be influenced by the regularity and intensity of outdoor exercise. Exercise choice for walking and individual-based exercise was less sensitive to the proximity of NOEs than the frequency of exercise: NOEs within 250–500 m of one's residence was associated with exercise frequency, while NOEs within 1.5 km was associated in choice. This reinforces existing literature of the importance of NOE proximity for physical exercise promotion (e.g., Akpinar, 2016; Pietilä et al., 2015; Toftager et al., 2011), but even more so to adhere to exercise routines, which fewer studies have compared. The physical exertion from the exercise could also affect how near a NOE should be to one's home. Lighter exercises such as walking had further buffer thresholds than more intensive exercises. In particular, unlike the other exercises, team-sports choice and frequency were associated with NOEs of immediate proximity (Figs. 2B and 4B). This could be due to team-sports being both a physically strenuous vigorous-intensity exercise, and one that requires the coordination with a group of people (Afsanepurak et al., 2012; Withall et al., 2011). Thus, physical exertion and the social dynamics of physical exercise are also important factors that influence the motivation to conduct and maintain levels of outdoor physical exercise.

Our study also found that investigating specific exercise types may be more informative than looking at overall exercise, as each exercise type had associations with different NOE type/s. This could be due to the similar number of respondents who engage in exercise associated with open-canopy (team-sports and individual-based) and closed-canopy (walking) vegetation in this study. There were also more types of exercise that were associated with managed vegetation (all exercises) than in areas with blue spaces (only individual-based). Looking at the overall findings may thus seem confusing and/or send wrong signal that NOEs with blue spaces may deter outdoor exercise frequency in the study's context (Figs. 2A and 4A). By reinforcing the differential effects of NOEs on the respective outdoor physical exercises, our study's findings can aid design of neighbourhood NOEs that caters to multiple physical exercises, thereby expanding public health benefits to a greater resident population.

4.2. Non-NOEs matter too: The relationship between socio-demographic factors and exercise

Amongst the overall population, more males, younger individuals, and those with higher perceived health exercised outdoors (Fig. 2). These results align with that of a nation-wide sports participation survey (Sports Singapore, 2016) and other studies where gender (Duncan et al., 2010; Guthold et al., 2018; Win et al., 2015), age (Uijtdewilligen et al., 2017; Win et al., 2015) and perceived health/fitness (Costello et al., 2011; Teixeira et al., 2012) strongly influenced physical exercise. This can be explained by differential social expectations/beliefs regarding fitness amongst genders (Duncan et al., 2010) and relative activity levels according to one's health and age (Teixeira et al., 2012). Gender and perceived health were also correlated with physical exercise frequency of those who exercised (Fig. 4), a group who are generally more motivated to keep fit as compared to the overall population (Duncan et al., 2010). This highlights the strength of health and gender-based stereotypes in influencing physical exercise habits, which can be a strong barrier for campaigns promoting physical activity. Measures should thus incorporate strategies to dispel and reduce the associated negativities of being female, older, or having lower fitness when it comes to exercising. Potential strategies could include offering exercise sessions/demonstrations catering to the community, elderly or females (e.g., Crofts et al., 2012; Murphy and Bauman, 2007), and preferably with exercise infrastructure to allow continuity beyond the sessions (Murphy and Bauman, 2007).

Financial capacity was also found to be a contributing factor. Having higher personal salaries was found to slightly characterise people who exercise outdoors (Fig. 2). Furthermore, less individuals with secondary or polytechnic diploma as the highest education qualification

conducted overall and individual-based exercises (Figs. 2A & C). These groups generally comprise of older, mid to senior-career working adults with lower income. While affordable exercise options such as outdoor jogging have the highest reach in Singapore (Sports Singapore, 2016), paid individual-based physical exercise classes such as swimming lessons, yoga and high-intensity interval training have been gaining traction (Teo, 2018), which may exclude working adults with lower cashflow. It is also possible that for team-sports, the investment of buying the sport-specific equipment (e.g., soccer ball) may be a deterrence to some. Such correlations between physical exercise and financial capacity aligns with previous studies (Trost et al., 2002; Withall et al., 2011), reinforcing the inequitable access to physical exercise, especially so for individual-based exercises. Campaigns could bridge this gap by promoting these individual-based exercises through subsidised or community/neighbourhood sessions (Withall et al., 2011). Frequency may be improved by promoting such sessions near workplaces to reduce the barrier of time in working adults (Barr-Anderson et al., 2011).

Gender was not retained in the model predicting walking frequency (Fig. 4C), which may be due to the relative ease of the usually light-intensity exercise. Perceived health was not retained in team-sports frequency (Fig. 4B), which could be due to the nature of having social accompaniment in these exercises, a strong motivation in physical exercise (Costello et al., 2011; Withall et al., 2011). This importance of social groups in sustaining team-sports exercise is something that future studies could consider investigating in greater detail, such as asking questions regarding the importance, presence, and strength of the social network in the team-sports exercise one participates in, especially if social cohesion is another factor decision-makers are interested in strengthening within their communities.

4.3. Limitations and future studies

Given the cross-sectional (rather than longitudinal) nature of this study, we are unable to draw causal relationships. It may be argued that we may also run into residential self-selection bias (Zang et al., 2019), where people who prefer to exercise in a certain type of NOE would choose to live near one, confounding the patterns between outdoor exercise and NOEs. This said, the housing allocation in Singapore creates conditions that reduces residential self-selection. Public housing, where 78.6% of Singaporeans reside in (Singapore Department of Statistics, 2018), are mainly released in quarterly one-week long sale exercises, in which the location, flat type, and quantity offered are limited. Housing offered in these exercises is often highly oversubscribed, and with each sales exercise offering housing from different locations,

geographical choice of public housing is restricted. Furthermore, public housing is also subjected to ethnic quotas to encourage racial integration, further reducing self-selection bias. Verifications of relationships derived from the nature of cross-sectional studies, which may be associative rather than causal, would however require experimental before-after studies.

In addition, we were neither able to determine the actual area of influence of different NOEs in each type of outdoor physical exercise (i.e., uncertain geographic context problem), nor the exact type or location of NOEs in which each respondent conducted their outdoor exercise. To minimise the geographical uncertainty effect of these limitations, we proposed multiple buffer ranges that covers the typical maximum distance one would travel from their residence to exercise in exercise facilities and/or parks (Halonen et al., 2015; Higgs et al., 2015; Kaczynski et al., 2014; Schipperijn et al., 2017). As we could not get the specific NOE locations, we utilised the next best alternative—correlating outdoor physical exercise habits with the NOEs within proximity of their residential place, which is a reasonable assumption given that the proximity of NOEs to individuals strongly influences whether physical exercise is conducted in such areas (Browning and Lee, 2017; Sturm and Cohen, 2014). Nevertheless, validation of our findings could be pursued by directly investigating the distance between locations of NOEs used for outdoor physical exercise from one's home, and associate this with the NOE's blue-green space cover (e.g., Brown et al., 2014).

Furthermore, finer resolution of features within these NOEs, such as amenities found in them (e.g., sports facilities, concrete paths), could also be incorporated in future analysis to further verify the effects of the landscape-level NOE cover variables that we used. This study took a step further from most existing literature by prying further into the provision of different NOE types at a macro-scale, which revealed nuanced preferences towards different green-blue spaces. Future studies could do this, and explore other key predictors of exercising in NOEs that have not been explored here. For example, on top of provisioning/availability, NOE accessibility could be explored through proxies such as transport options available (Lee and Moudon, 2008; Pietilä et al., 2015). Awareness of the NOEs (e.g., perceived proximity of it (Schipperijn et al., 2017)), and presence of physical exercise-promoting facilities within them, such as tracks and trails, lighting and signage (Lee and Moudon, 2008; Schipperijn et al., 2013), or presence of alternative indoor exercise spaces within the buffer size of interest (e.g., Pietilä et al., 2015), could also be incorporated. This inclusion could reinforce the knowledge gleaned from our study, where knowledge of specific type/mixes of NOEs within proximity of one's residence can be used to support the development of exercise-promoting

public spaces. In Singapore's context, our findings partially supports, and thus reinforces the necessity to adhere to the national land use target plan of incorporating parks within 500 m of 90% of residents' homes by 2030 (Urban Redevelopment Authority, 2019). Urban planners could thus consider integrating a variety of NOEs within these parks, such as unmanaged vegetation patches amongst the urban landscape, open-canopy grass turfs, and/or waterfront parks with both blue spaces and managed green spaces, to serve the dual purpose of enhancing ecological resilience and promoting public health and wellbeing.

5. Conclusions

Overall, our study provided a finer scale investigation of the correlation between urban green and blue spaces in NOEs and outdoor physical exercise. By doing so, we yielded insights into how the population of a tropical country, which has high NOE cover and variety in its highly developed city, may utilise different NOE types for multiple outdoor physical exercises. A novel insight of more nuanced correlations between NOEs and outdoor exercise was uncovered, suggesting the potential of specific types and combinations of NOEs in promoting outdoor exercise, be it managed green spaces, or combinations of different unmanaged types, blue-and-green, or managed-unmanaged NOEs. This study thus not only serves as evidence of the need for finer-resolution categories of NOEs and physical exercise types, but can also guide urban planners in amalgamating ecological knowledge into urban landscape designs to better address a public health issue of high concern.

CRediT authorship contribution statement

Claudia L.Y. Tan: Conceptualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Chia-Chen Chang:** Conceptualization, Writing - review & editing. **Le T.P. Nghiem:** Conceptualization, Data curation, Writing - review & editing. **Yuchen Zhang:** Writing - review & editing. **Rachel R.Y. Oh:** Conceptualization, Data curation Methodology, Writing - review & editing, Funding acquisition. **Danielle F. Shanahan:** Writing - review & editing. **Brenda B. Lin:** Writing - review & editing. **Kevin J. Gaston:** Writing - review & editing. **Richard A. Fuller:** Writing - review & editing. **L. Roman Carrasco:** Conceptualization, Funding acquisition, Supervision, Writing - review & editing.

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.

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