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### Promoting physical activity: The role of neighbourhood safety and renewal of deprived areas

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# CHAPTER

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# 4

## **Associations of changes in neighbourhood safety with leisure-time physical activity: evidence for the role of residential self-selection**

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## ABSTRACT

**Purpose** Evidence on the relation between neighbourhood safety and physical activity has primarily been derived from cross-sectional studies, which are vulnerable to residential self-selection bias. This study aimed to assess the role of residential self-selection in the relation between neighbourhood safety and leisure-time physical activity (LTPA) among Dutch adults.

**Methods** Data on LTPA were obtained from the Dutch Health Interview Survey 2009-2011. Data on self-reported neighbourhood safety were obtained from the National Safety Monitor 2005-2008 (P1) and the Integrated Safety Monitor 2008-2011 (P2). Multilevel logistic regression analyses (N=15 608 adults) were used to assess associations of LTPA with levels of neighbourhood safety in P1 and with changes in neighbourhood safety between P1 and P2. Results of both analyses were compared to assess the role of residential self-selection.

**Results** Leisure-time walking was negatively associated with levels of social order and non-victimization, but not associated with levels of general safety and physical order. Associations were about equally strong for changes in neighbourhood safety. Leisure-time cycling was positively associated with levels of all four safety indicators and with changes therein, though these latter associations were weaker. Leisure-time sports was positively associated with levels of all four safety indicators, but only with changes in social order and non-victimization.

**Conclusions** Leisure-time cycling and sports were less strongly associated with changes in neighbourhood safety than with levels of neighbourhood safety. This suggests that residential self-selection explains a substantial part of the relation between neighbourhood safety and leisure-time cycling and sports.

**Keywords** physical activity, leisure time, neighbourhood, safety, crime, disorder, self-selection

## INTRODUCTION

There is ample evidence that physical inactivity is detrimental for health [1]. Despite this evidence, 31% of adults worldwide do not meet current guidelines for physical activity (PA) [2]. To achieve population-level improvements in PA, social-ecological models suggest implementing multilevel interventions that do not only address PA determinants at the individual level, but also at the environmental level [3-5]. Various reviews have found PA to be consistently associated with several neighbourhood characteristics, including aesthetics, pedestrian infrastructure, and recreational facilities [6-11].

There is less consistent evidence for the role of neighbourhood safety in PA [12]. Some studies found no evidence of an association, while others found evidence of a positive association [12]. A positive association may indicate that living in a safe neighbourhood stimulates PA and that living in an unsafe neighbourhood hinders PA. Safety concerns may cause stress and fear, which adults may try to alleviate by avoiding potentially dangerous places, thereby decreasing their levels of PA [13-15]. Residential self-selection has been raised as an alternative reason for the positive association between neighbourhood safety and PA. Self-selection entails that adults who are active or willing to be active go live in safe neighbourhoods that facilitate PA [16,17]. Hence, high levels of PA in safe neighbourhoods may not be the result of adults getting more active because of better safety, but of active adults moving into safe neighbourhoods. So far, the majority of studies on neighbourhood safety and PA have been cross-sectional [12,18]. These studies are vulnerable to residential self-selection bias and may therefore overestimate the causal effect of neighbourhood safety on PA [16,17,19].

There is only limited understanding of the role of residential self-selection in the relation between neighbourhood safety and PA. A few studies have taken self-selection into account by assessing associations of PA with *changes* in neighbourhood safety over time. This study design minimizes the chance of self-selection bias by controlling for factors that remain stable over time, including residential preferences [19]. In Australia, Humpel et al. [20] explored to what extent individuals' perceptions of changes in traffic safety were associated with changes in walking during a 10-week period. Men who reported positive changes in traffic safety were less likely to have increased their walking, while women were more likely to have increased their walking. In the Netherlands, Jongeneel-Grimen et al. [21,22] explored to what extent neighbourhood-wide perceptions of changes in various neighbourhood safety indicators were associated with PA afterwards. More favourable changes in traffic safety, crime safety, physical order, and social order over time were associated with

higher odds of PA. These studies provide evidence to suggest that neighbourhood safety may be associated with PA beyond residential self-selection.

Additional research along the lines of Jongeneel-Grimen et al. [21,22] is needed with more specific PA measures, because neighbourhood environmental correlates of PA have been found to differ according to the purpose (i.e. leisure or transport) and type (e.g. walking, cycling) of PA [6,8,9,11]. The current study aimed to assess to what extent associations between neighbourhood safety and specific types of leisure-time physical activity (LTPA) in Dutch adults could be explained by residential self-selection. We explored associations of leisure-time walking, cycling, and sports with levels of neighbourhood safety at one point in time and with changes in neighbourhood safety over time. Four indicators of neighbourhood safety were included: general safety, physical order, social order, and non-victimization. Results for safety levels were compared with those for safety changes to assess the role of residential self-selection. Based on the assumption that part of the safety-LTPA relation is due to residential self-selection, we expected LTPA to be less strongly associated with safety changes than with safety levels.

Previous studies have suggested that neighbourhood safety may be more strongly associated with PA in women, elderly people, and people with a lower socio-economic status [12,18]. Therefore, in case we found neighbourhood safety to be related with LTPA beyond residential self-selection, we also explored whether the relation differed by age, gender, and educational level. We expected LTPA to be more strongly associated with safety changes among women, older adults, and lower educated adults.

## **METHODS**

This study was based on secondary analyses of anonymized survey data provided by Statistics Netherlands (the "CBS"). The Medical Ethics Committee of the Academic Medical Centre in Amsterdam, the Netherlands, has confirmed that the Dutch Medical Research Involving Human Subjects Act (WMO) does not apply to this study (reference number W14\_150 # 14.17.0187). Therefore, no official ethics approval was required.

### **Data**

Repeated cross-sectional data on LTPA and potential confounders were obtained from the Dutch Health Interview Survey (*Gezondheidsenquête*) 2009-2011. Each year, a random nationwide sample of non-institutionalized individuals of all ages was drawn

from the national population registry. Selected individuals were interviewed at home (2009) or asked to fill in an online survey (2010, 2011). In 2010 and 2011, non-respondents were approached by telephone or interviewer. In addition to the basic survey, individuals of 12 years and older were asked to complete a supplementary survey about specific health topics, including LTPA. Respondents were able to fill in the supplementary survey on paper (2009-2011) or online (2010,2011). Between 2009 and 2011, a total of about 45 000 individuals were approached with the basic survey. Non-response was 35-40%. Of the remaining individuals of 12 years and older, non-response to the supplementary survey was 20% (2009) and 45% (2010,2011). Respondents were excluded when they were under 18 years old or had no zip code information. A total remained of 18 255 adults.

Repeated cross-sectional data on neighbourhood safety were obtained from the National Safety Monitor (*Veiligheidsmonitor Rijk*) (NSM) 2005-2008 and its successor the Integrated Safety Monitor (*Integrale Veiligheidsmonitor*) (ISM) 2008-2011. For both surveys, data were collected at a national level. For the ISM, additional data were collected at the local level every two years. We only included data collected at the national level to increase comparability of the data over the years. For the national data collection of both surveys, monthly random nationwide samples of non-institutionalized individuals of 15 years and older were drawn from the national population registry using a two-step design, with sub-municipalities in step one and individuals in step two. For the NSM, individuals were approached by telephone or interviewer between January and March. For the ISM, individuals were sent a letter between mid-September and December in which they were asked to fill in an online survey or paper-and-pencil survey. Non-respondents were approached by telephone or interviewer. Between 2005 and 2011, a total of 226 165 individuals were approached. Non-response was 38%. Respondents were excluded when they were under 18 years old, had no personal identification number, or had no zip code information. A total remained of 133 522 adults.

## Measures

### LTPA

LTPA was measured using the Dutch Short QQuestionnaire to ASsess Health-enhancing physical activity (SQUASH). This instrument has shown to be fairly reliable and valid for measuring PA [23,24]. Respondents were asked to report the duration (hours and minutes per day) and frequency (days per week) of leisure-time walking, cycling, and up to four different sports. Water-related sports (e.g. skiing, surfing, diving), agility sports (e.g. bowling, darts, golf) and mental sports (e.g. chess) were excluded. Total minutes per week spent on leisure-time walking, cycling, and total amount of sports were calculated by multiplying duration and frequency. Individuals were excluded

when total score exceeded 3 360 minutes per week. As the distribution of the three LTPA outcomes was highly skewed, LTPA was dichotomised into 'inactive' (no minutes per week) versus 'active' (any minutes per week). Sensitivity analyses were performed to assess whether results were different using higher cut-off points for LTPA (i.e. 30 and 60 minutes per week).

### Neighbourhood safety

Neighbourhood safety was measured using four indicators:

- *Perceived general safety.* Respondents were asked whether they sometimes felt unsafe in their own neighbourhood. They were able to answer 'yes' (0) or 'no' (1).
- *Perceived physical order:* Respondents were asked whether they judged graffiti, litter, dog waste, and demolition of phone booths/bus-cubicles/tram-cubicles to occur often (1), sometimes (2), or (almost) never (3) in their neighbourhood. We calculated the average score on all four items (range 1-3). Cronbach's alpha of the four items was 0.61, indicating fair reliability.
- *Perceived social order.* Respondents were asked whether they judged youth nuisance, drugs nuisance, neighbour nuisance, drunk people on the street, and harassment of people on the street to occur often (1), sometimes (2), or (almost) never (3) in their neighbourhood. We calculated the average score on all five items (range 1-3). Cronbach's alpha of the five items was 0.68, indicating fair reliability.
- *Criminal non-victimization.* Respondents were asked whether they had been a victim in the past five years of attempted burglary, burglary, bicycle theft, car theft, theft from their car, car damaging, pick pocketing, violent robbery, other thefts, other damaging, sexual abuse, threat of physical abuse, physical abuse, other crimes. If respondents were victimized, they were asked if that happened before or after January 1<sup>st</sup> of last year (NSM), or this year, last year, or earlier (ISM). If respondents were victimized after January 1<sup>st</sup> of last year (NSM) or this year (ISM) they were asked whether the last time occurred in their own neighbourhood, somewhere else in the municipality, somewhere else in the Netherlands, or in a foreign country. For each of the fourteen crimes, respondents were given a score of 1 if they had been victimized in their own neighbourhood after January 1<sup>st</sup> of last year (NSM) or this year (ISM). All other respondents were given a score of 0. An overall non-victimization variable was computed by summing the scores of all fourteen crimes (range 0-14).

First, for each safety indicator, *levels* of neighbourhood safety were calculated by aggregating all individual scores within period 1 (P1: 2005-2008, NSM) and those in period 2 (P2: 2008-2011, ISM) at the neighbourhood level. For general safety and non-victimization, neighbourhood-level scores were obtained by calculating the percentage of residents within the neighbourhood that felt safe or were not

victimized, respectively, in P1 and P2 (range 0-100). For physical and social order, neighbourhood-level scores were obtained by averaging all individual scores within the neighbourhood in P1 and P2 (range 1-3). A neighbourhood was defined as the area within one 4-digit zip code. Neighbourhood-level variables were standardized using z-scores to increase comparability across safety indicators. To accurately assess neighbourhood-level perceptions, neighbourhoods were excluded when neighbourhood-level scores were based on less than 10 valid scores or less than 2 years per period. Sensitivity analyses were performed to assess whether results were different using higher cut-off points for neighbourhood-level safety (i.e. 20 valid scores or less than 2 years per period).

Second, for each safety indicator, *changes* in neighbourhood safety over time were calculated by subtracting neighbourhood-level scores in P1 from those in P2. A negative score indicated a worsening of neighbourhood safety between periods, a score of 0 indicated no change, and a positive score indicated an improvement of neighbourhood safety between periods. Neighbourhoods were excluded when one of the period averages was missing.

Finally, safety levels and safety changes were linked to the Dutch Health Interview Survey data using data on the 4-digit zip code. Individuals were excluded from the Dutch Health Interview Survey when no data on safety change were available. A total remained of between 15 392 and 15 608 adult respondents residing in 1931 to 1938 neighbourhoods (depending on the safety measure and LTPA outcome).

### Covariates

Data on age (continuous), gender (men, women), household composition (four combinations of partner or single and children or no children), and educational level (primary, lower secondary, higher secondary, tertiary) were obtained from the Dutch Health Interview Survey. Data on ethnicity (ethnic Dutch, and three non-ethnic Dutch groups: Western, non-Western, origin unknown) were derived from the national population registry. Data on equivalent disposable household income (quintiles) were obtained from the national tax registry.

### **Statistical analyses**

Logistic regression analyses were applied to assess to what extent the odds of doing any leisure-time walking, cycling, or sports in 2009-2011 (P2) were associated with levels of neighbourhood safety in P1 and with changes in neighbourhood safety between P1 and P2. Safety levels and safety changes were included in the model simultaneously. Separate analyses were performed for each safety indicator and LTPA outcome. Analyses were adjusted for age, gender, ethnicity, household composition,

educational level, and household income. Multilevel regression analyses were applied to take clustering of respondents in neighbourhoods into account. Level 1 represented individuals and level 2 represented neighbourhoods.

First, we estimated associations for the total adult population. Then, we estimated associations for subgroups of gender (men; women), age (under 55 years old; 55 years and older), and educational level (primary and lower secondary level; higher secondary and tertiary level). These estimates were derived by simultaneously adding interaction terms of neighbourhood safety levels with the subgroup of interest and of neighbourhood safety changes with the subgroup of interest. All analyses were carried out using STATA 11.0 software. Statistical significance was set at 0.05. Results that were marginally statistically significant (i.e. with a p-value between 0.05 and 0.10) were also presented.

## RESULTS

Neighbourhood-wide perceptions of general safety, physical order, and social order deteriorated between P1 and P2 (Table 1). On the contrary, between P1 and P2 there was an increase in the number of adults who had never been victimized. The degree to which neighbourhood safety changed between P1 and P2 varied between neighbourhoods. For example, the degree of change in non-victimization varied from a decrease of about 3% in neighbourhoods at the 25<sup>th</sup> percentile, to an increase of about 9% in neighbourhoods at the 75<sup>th</sup> percentile.

TABLE 1. Characteristics of neighbourhood safety levels in the periods 2005-2008 (P1) and 2008-2011 (P2), and of changes in neighbourhood safety between the periods 2005-2008 and 2008-2011 ( $\Delta$ P1-P2) (unstandardized)

	General safety <sup>1</sup>	Physical order <sup>2</sup>	Social order <sup>2</sup>	Non-victimization <sup>1</sup>
<b>P1</b>				
Mean	92.07	2.35	2.75	81.66
Standard deviation	7.31	0.19	0.12	9.48
25 <sup>th</sup> percentile	88.24	2.23	2.70	76.47
75 <sup>th</sup> percentile	97.37	2.48	2.83	88.24
<b>P2</b>				
Mean	84.40	2.27	2.65	84.60
Standard deviation	10.17	0.18	0.16	8.65
25 <sup>th</sup> percentile	78.72	2.14	2.57	80.00
75 <sup>th</sup> percentile	91.84	2.40	2.75	90.91
<b><math>\Delta</math> P1-P2</b>				
Mean	-7.67	-0.08	-0.11	2.95
Standard deviation	8.82	0.13	0.11	10.08
25 <sup>th</sup> percentile	-12.63	-0.16	-0.16	-3.33
75 <sup>th</sup> percentile	-1.68	0.00	-0.04	9.09

<sup>1</sup>Percentage of respondents feeling safe/not victimized

<sup>2</sup>Mean score between 1 (never order) and 3 ((almost) always order)

TABLE 2. Associations of LTPA in P2 with individual characteristics, with neighbourhood safety levels in the period 2005-2008 (P1), and with changes in neighbourhood safety between the periods 2005-2008 and 2008-2011 ( $\Delta$ P1-P2) (z-scores)

	% N <sup>1</sup>	Odds Ratio's for being active in leisure time in P2 (95% CI) <sup>2</sup>		
		Walking	Cycling	Sports
<b>Individual characteristics</b>				
<b>Age (years, mean)</b>	50.8	1.01 (1.00 - 1.01)**	1.00 (0.99 - 1.00)	0.97 (0.97 - 0.98)**
<b>Gender</b>				
Women	47.6	Ref	Ref	Ref
Men	52.4	1.59 (1.48 - 1.70)**	1.24 (1.16 - 1.33)**	1.13 (1.05 - 1.20)**
<b>Household composition</b>				
Partner/married with child(ren)	35.3	Ref	Ref	Ref
Partner/married no child(ren)	41.0	1.07 (0.98 - 1.17)	0.98 (0.90 - 1.07)	1.07 (0.98 - 1.16)
Single no child(ren)	18.4	0.88 (0.80 - 0.98)**	0.75 (0.67 - 0.83)**	1.13 (1.01 - 1.25)**
Single with child(ren)	4.0	0.70 (0.59 - 0.84)**	0.83 (0.70 - 0.99)**	0.94 (0.79 - 1.12)
<b>Ethnicity</b>				
Ethnic Dutch	87.4	Ref	Ref	Ref
Non-ethnic Dutch, western	6.0	0.90 (0.78 - 1.03)	0.75 (0.65 - 0.86)**	1.16 (1.01 - 1.34)**
Non-ethnic Dutch, non-western	1.9	0.89 (0.69 - 1.14)	0.52 (0.40 - 0.66)**	0.73 (0.56 - 0.94)**
Non-ethnic Dutch, origin unknown	3.4	0.89 (0.74 - 1.07)	0.57 (0.47 - 0.68)**	0.96 (0.80 - 1.16)
<b>Educational level</b>				
Primary	12.7	Ref	Ref	Ref
Secondary: lower level	22.7	1.47 (1.31 - 1.65)**	1.54 (1.37 - 1.73)**	1.60 (1.40 - 1.82)**
Secondary: higher level	30.6	1.84 (1.64 - 2.07)**	1.81 (1.61 - 2.04)**	2.13 (1.87 - 2.42)**
Tertiary	29.4	2.48 (2.19 - 2.81)**	2.46 (2.17 - 2.78)**	2.96 (2.59 - 3.39)**
<b>Household income (€)</b>				
1 <sup>st</sup> quintile (<17 197)	19.7	Ref	Ref	Ref
2 <sup>nd</sup> quintile (17 197 - 21 517)	19.9	1.16 (1.04 - 1.29)**	1.04 (0.94 - 1.16)	1.30 (1.16 - 1.46)**
3 <sup>rd</sup> quintile (21 518 - 26 213)	20.0	1.22 (1.09 - 1.36)**	1.04 (0.94 - 1.16)	1.54 (1.37 - 1.72)**
4 <sup>th</sup> quintile (26 214 - 33 098)	20.1	1.09 (0.97 - 1.21)	0.96 (0.86 - 1.07)	1.76 (1.57 - 1.98)**
5 <sup>th</sup> quintile (>33 098)	20.0	1.14 (1.02 - 1.29)**	0.99 (0.86 - 1.11)	2.21 (1.97 - 2.49)**
<b>Neighbourhood safety P1</b>				
General safety	92.07	0.97 (0.93 - 1.01)	1.12 (1.08 - 1.16)**	1.07 (1.03 - 1.11)**
Physical order	2.35	0.97 (0.94 - 1.01)	1.10 (1.05 - 1.14)**	1.07 (1.03 - 1.11)**
Social order	2.75	0.96 (0.93 - 0.99)**	1.07 (1.03 - 1.11)**	1.06 (1.02 - 1.10)**
Non-victimization	81.66	0.94 (0.90 - 0.99)**	1.06 (1.01 - 1.11)**	1.06 (1.02 - 1.11)**
<b>Neighbourhood safety <math>\Delta</math> P1-P2</b>				
$\Delta$ General safety	-7.67	0.99 (0.96 - 1.03)	1.07 (1.03 - 1.11)**	1.02 (0.98 - 1.05)
$\Delta$ Physical order	-0.08	1.01 (0.97 - 1.05)	1.06 (1.02 - 1.10)**	1.01 (0.97 - 1.05)
$\Delta$ Social order	-0.11	0.97 (0.94 - 1.01)*	1.03 (0.99 - 1.07)*	1.03 (0.99 - 1.07)*
$\Delta$ Non-victimization	2.95	0.95 (0.91 - 0.99)**	1.04 (0.99 - 1.09)*	1.05 (1.00 - 1.09)**

<sup>1</sup>Percentages may not add up to 100% due to the category 'missings' which has not been reported. Characteristics represent average values over the years 2005-2011.

<sup>2</sup>Individual characteristics, neighbourhood safety P1, and neighbourhood safety  $\Delta$ P1-P2 were all included in the model. Separate models were used for each safety indicator and LTPA outcome.

\*\*p<0.05; \*0.05<p<0.10

The upper part of table 2 displays associations of LTPA in P2 with individual-level factors. Odds of LTPA were generally higher among men, couples, adults of Dutch origin, higher educated adults, and adults with higher income levels. Increasing age was associated with increased odds of walking, but decreased odds of sports participation. The middle part of table 2 displays associations of LTPA in P2 with levels of neighbourhood safety in P1. For leisure-time walking, higher levels of social order and non-victimization were associated with lower odds of being active. There were no associations with levels of general safety and physical order. For both leisure-time cycling and sports, higher levels of all four safety indicators were associated with higher odds of being active.

The bottom part of table 2 displays associations of LTPA in P2 with changes in neighbourhood safety between P1 and P2. For leisure-time walking, greater improvements in social order and non-victimization over time were associated with lower odds of being active. There were no associations with changes in general safety and physical order. For leisure-time cycling, greater improvements in all four safety indicators over time were associated with higher odds of being active. For leisure-time sports, greater improvements in social order and non-victimization over time were associated with higher odds of being active. There were no associations with changes in general safety and physical order. A comparison of results displayed in the middle and bottom part of table 2 reveals that leisure-time cycling and sports were less strongly associated with changes in neighbourhood safety between P1 and P2 than with levels of neighbourhood safety in P1. For leisure-time walking, no such differences were apparent. Differences were apparent for all safety indicators, but least for non-victimization.

Table 3 displays associations of LTPA in P2 with changes in neighbourhood safety between P1 and P2, stratified by subgroup. Several (marginally) significant interactions were found. Leisure-time walking was more positively associated with changes in physical order among women, and more negatively associated with changes in general safety among older adults. Leisure-time cycling was more positively associated with changes in physical order among women, with changes in non-victimization among men, with changes in general safety and non-victimization among older adults, and with changes in non-victimization among lower educated adults. Leisure-time sports was more positively associated with changes in physical order among women, with changes in social order among older adults, and with changes in all safety indicators except physical order among lower educated adults. Thus, when interactions were observed, associations were generally stronger among women, older adults, and lower educated adults.

TABLE 3. Associations of LTPA in P2 with changes in neighbourhood safety between the periods 2005-2008 and 2008-2011 ( $\Delta P1-P2$ ) (z-scores), stratified by subgroup

	Odds Ratio's for being active in leisure time in P2 (95% CI) <sup>1</sup>		
	Walking	Cycling	Sports
<b>Gender</b>			
<b>Men (ref)</b>			
$\Delta$ General safety	0.97 (0.93 - 1.02)	1.05 (1.00 - 1.10)*	0.99 (0.94 - 1.04)
$\Delta$ Physical order	0.96 (0.91 - 1.01)	1.01 (0.96 - 1.07)	0.96 (0.91 - 1.01)
$\Delta$ Social order	0.98 (0.93 - 1.03)	1.01 (0.96 - 1.07)	1.03 (0.98 - 1.08)
$\Delta$ Non-victimization	0.97 (0.91 - 1.03)	1.09 (1.02 - 1.16)**	1.04 (0.97 - 1.10)
<b>Women</b>			
$\Delta$ General safety	1.01 (0.96 - 1.06)	1.08 (1.03 - 1.14)**	1.04 (0.99 - 1.09)*
$\Delta$ Physical order	1.06 (1.01 - 1.12)**†	1.11 (1.05 - 1.17)**†	1.06 (1.00 - 1.11)**†
$\Delta$ Social order	0.96 (0.92 - 1.01)	1.05 (1.00 - 1.10)**	1.03 (0.98 - 1.08)
$\Delta$ Non-victimization	0.93 (0.88 - 0.99)**	1.00 (0.94 - 1.07)‡	1.06 (1.00 - 1.13)*
<b>Age<sup>2</sup></b>			
<b>Younger (ref)</b>			
$\Delta$ General safety	1.03 (0.98 - 1.07)	1.04 (0.99 - 1.09)	1.01 (0.96 - 1.05)
$\Delta$ Physical order	1.02 (0.97 - 1.07)	1.05 (1.00 - 1.10)*	1.00 (0.96 - 1.05)
$\Delta$ Social order	0.97 (0.92 - 1.01)	1.02 (0.98 - 1.07)	1.01 (0.97 - 1.05)
$\Delta$ Non-victimization	0.95 (0.90 - 1.01)*	0.98 (0.93 - 1.04)	1.02 (0.97 - 1.08)
<b>Older</b>			
$\Delta$ General safety	0.94 (0.89 - 0.99)**†	1.10 (1.05 - 1.17)**‡	1.03 (0.98 - 1.09)
$\Delta$ Physical order	1.00 (0.94 - 1.05)	1.07 (1.01 - 1.13)**	1.02 (0.96 - 1.08)
$\Delta$ Social order	0.97 (0.92 - 1.03)	1.05 (0.99 - 1.11)*	1.07 (1.01 - 1.13)**‡
$\Delta$ Non-victimization	0.94 (0.88 - 1.00)*	1.14 (1.07 - 1.22)**†	1.09 (1.02 - 1.17)**
<b>Educational level<sup>3</sup></b>			
<b>Higher level (ref)</b>			
$\Delta$ General safety	0.98 (0.94 - 1.03)	1.05 (1.00 - 1.10)**	0.99 (0.94 - 1.03)
$\Delta$ Physical order	1.02 (0.97 - 1.07)	1.04 (0.99 - 1.10)*	0.99 (0.94 - 1.04)
$\Delta$ Social order	0.96 (0.92 - 1.01)	1.02 (0.98 - 1.07)	1.01 (0.97 - 1.06)
$\Delta$ Non-victimization	0.95 (0.90 - 1.01)	0.98 (0.93 - 1.04)	1.03 (0.97 - 1.08)
<b>Lower level</b>			
$\Delta$ General safety	0.99 (0.93 - 1.05)	1.10 (1.04 - 1.17)**	1.11 (1.05 - 1.19)**†
$\Delta$ Physical order	0.98 (0.92 - 1.04)	1.08 (1.02 - 1.15)**	1.05 (0.99 - 1.13)
$\Delta$ Social order	0.97 (0.92 - 1.03)	1.06 (1.00 - 1.12)**	1.10 (1.03 - 1.17)**†
$\Delta$ Non-victimization	0.93 (0.86 - 1.00)**	1.17 (1.09 - 1.27)**†	1.15 (1.06 - 1.24)**†

<sup>1</sup>Adjusted for age, gender, household composition, ethnicity, educational level, household income, and an interaction term of neighbourhood safety P1 with the subgroup of interest. Separate models were used for each safety indicator and LTPA outcome.

<sup>2</sup>Younger = under 55 years old; older = 55 years and older.

<sup>3</sup>Higher = higher secondary and tertiary level; lower = primary and lower secondary level.

\*\*p $\leq$ 0.05; \*0.05<p $\leq$ 0.10

†interaction p $\leq$ 0.05; ‡interaction 0.05<p $\leq$ 0.10

Table 4 displays associations of LTPA in P2 with changes in neighbourhood safety between P1 and P2, using different cut-off points for LTPA and neighbourhood safety. The top part of table 4 displays results for different cut-off points for LTPA. Results for the 30 and 60 minutes per week cut-off point were similar to those for the initial 0 minutes per week cut-off point. The only exception being that leisure-time cycling was

less strongly associated with changes in general safety and physical order when using the higher cut-off points. However, associations remained statistically significant.

The bottom part of table 4 displays results for different cut-off points for neighbourhood-level safety. For leisure-time cycling, results for the cut-off point of 20 valid safety scores per period were similar to those for the initial cut-off point of 10 valid safety scores per period. Leisure-time walking was no longer marginally significantly associated with changes in social order using the higher cut-off point, while it turned out to be marginally significantly associated with changes in physical order. Leisure-time sports was no longer associated with changes in any of the safety indicators when using the higher cut-off point.

TABLE 4. Associations of LTPA in P2 with changes in neighbourhood safety between the periods 2005-2008 and 2008-2011 ( $\Delta P1-P2$ ) (z-scores), sensitivity analyses

Neighbourhood safety $\Delta P1-P2$	Odds Ratio's for being active in leisure time in P2 (95% CI) <sup>2</sup>		
	Walking	Cycling	Sports
<b>Alternative cut-off points for LTPA</b>			
<b>0 minutes per week</b>			
$\Delta$ General safety	0.99 (0.96 – 1.03)	1.07 (1.03 – 1.11)**	1.02 (0.98 – 1.05)
$\Delta$ Physical order	1.01 (0.97 – 1.05)	1.06 (1.02 – 1.10)**	1.01 (0.97 – 1.05)
$\Delta$ Social order	0.97 (0.94 – 1.01)*	1.03 (1.00 – 1.07)*	1.03 (0.99 – 1.07)*
$\Delta$ Non-victimization	0.95 (0.91 – 0.99)**	1.04 (1.00 – 1.09)*	1.05 (1.00 – 1.09)**
<b>30 minutes per week</b>			
$\Delta$ General safety	0.98 (0.95 – 1.02)	1.05 (1.01 – 1.09)**	1.02 (0.98 – 1.05)
$\Delta$ Physical order	1.01 (0.97 – 1.05)	1.06 (1.02 – 1.10)**	1.01 (0.98 – 1.05)
$\Delta$ Social order	0.97 (0.94 – 1.01)*	1.03 (1.00 – 1.07)*	1.03 (1.00 – 1.07)*
$\Delta$ Non-victimization	0.95 (0.91 – 0.99)**	1.04 (0.99 – 1.08)	1.05 (1.00 – 1.09)**
<b>60 minutes per week</b>			
$\Delta$ General safety	0.99 (0.95 – 1.02)	1.04 (1.00 – 1.08)**	1.02 (0.98 – 1.05)
$\Delta$ Physical order	1.00 (0.97 – 1.04)	1.04 (1.00 – 1.08)**	1.01 (0.98 – 1.05)
$\Delta$ Social order	0.97 (0.93 – 1.00)*	1.03 (0.99 – 1.06)	1.04 (1.00 – 1.08)**
$\Delta$ Non-victimization	0.95 (0.91 – 1.00)**	1.03 (0.99 – 1.08)	1.04 (1.00 – 1.09)*
<b>Alternative cut-off points for neighbourhood safety <math>\Delta P1-P2</math></b>			
<b>10 valid safety scores per period</b>			
$\Delta$ General safety	0.99 (0.96 – 1.03)	1.07 (1.03 – 1.11)**	1.02 (0.98 – 1.05)
$\Delta$ Physical order	1.01 (0.97 – 1.05)	1.06 (1.02 – 1.10)**	1.01 (0.97 – 1.05)
$\Delta$ Social order	0.97 (0.94 – 1.01)*	1.03 (0.99 – 1.07)*	1.03 (0.99 – 1.07)*
$\Delta$ Non-victimization	0.95 (0.91 – 0.99)**	1.04 (0.99 – 1.09)*	1.05 (1.00 – 1.09)**
<b>20 valid safety scores per period</b>			
$\Delta$ General safety	1.00 (0.96 – 1.05)	1.07 (1.02 – 1.11)**	1.01 (0.97 – 1.05)
$\Delta$ Physical order	1.04 (1.00 – 1.09)*	1.07 (1.02 – 1.11)**	0.99 (0.94 – 1.03)
$\Delta$ Social order	1.01 (0.97 – 1.05)	1.05 (1.01 – 1.10)**	1.03 (0.99 – 1.07)
$\Delta$ Non-victimization	0.95 (0.90 – 1.01)*	1.03 (0.98 – 1.09)	1.02 (0.97 – 1.07)

<sup>1</sup>Adjusted for age, gender, household composition, ethnicity, educational level, household income, and neighbourhood safety P1. Separate models are used for each safety indicator and LTPA outcome.

\*\* $p \leq 0.05$ ; \* $0.05 < p \leq 0.10$

## DISCUSSION

The overall aim of this study was to explore to what extent associations of self-reported neighbourhood safety with LTPA in Dutch adults could be explained by residential self-selection. We explored the role of self-selection by assessing associations between LTPA and levels of neighbourhood safety at one point in time, and by comparing them with associations between LTPA and changes in neighbourhood safety over time. Leisure-time walking was negatively associated with both levels of and changes in social order and non-victimization, but not with levels of or changes in general safety or physical order. Leisure-time cycling was positively associated with levels of all four safety indicators, as well as with changes therein, though these latter associations were substantially weaker than the first. Leisure-time sports was positively associated with levels of all four safety indicators, but only with changes in social order and non-victimization.

### Limitations

Several methodological considerations need to be taken into account when interpreting the results of this study. In 2008, some alterations were made to the survey that was used to measure perceptions of neighbourhood safety. The phrasing of the questions that were relevant for this study remained unchanged, but their order slightly changed and the main survey mode changed from telephone to internet. This may have caused us to misestimate absolute changes in neighbourhood safety over time. However, this would have only biased our results if the error systematically differed by levels of LTPA or neighbourhood safety, which we do not consider to be very likely.

While we included a wide variety of potential individual-level confounders, we were unable to account for residual neighbourhood-level confounding. Our results may have been biased if neighbourhoods changed in ways related to both neighbourhood safety and LTPA. The mechanisms underlying changes in neighbourhood safety are complex and hard to quantify. Therefore, we were unable to include all relevant neighbourhood-level confounders. To address this problem, future studies are advised to adopt a quasi-experimental design, thereby exploring changes in LTPA in neighbourhoods where safety levels changed because of specific programmes or policies.

We only had individual-level data on LTPA in P2, and not on LTPA in P1 and P2. Longitudinal data would have allowed us to look at changes in individual-level LTPA over time in relation to changes in neighbourhood safety over time. By doing so, we would have been better able to account for baseline levels of LTPA.

LTPA has been assessed using survey data, which has been associated with issues like social desirability and recall errors [25]. As a result, levels of PA are generally over-reported in surveys [26]. However, this will have only affected our results if the degree of over-reporting systematically differed by levels of or changes in neighbourhood safety, which is unlikely. Another issue is that the survey did not provide information about the location where adults were active. By including LTPA activities that were performed within as well as outside the neighbourhood of residence, we may have underestimated some of the associations between safety changes and LTPA.

Most of the neighbourhood safety indicators that we used represented adults' perceptions of safety. Research has shown that people's perception of their neighbourhood is generally poorly correlated with objectively measured neighbourhood features [27-29]. We chose to use perceptions of neighbourhood safety in this study. While safety problems may objectively be resolved over time, adults will remain fearful and constrain their behaviour as long as they do not perceive that these problems have been resolved. Research has found evidence to suggest that neighbourhood perceptions may indeed be more strongly associated with PA than the objective neighbourhood environment [29]. People who perceived their objectively measured high walkable neighbourhood as low walkable, were found to decrease their transport walking significantly more than those with matched perceptions [29].

### **Interpretation of key findings**

Leisure-time cycling and sports were substantially less strongly associated with changes in neighbourhood safety over time than with levels of neighbourhood safety at one point in time. Our findings are in line with earlier research by Jongeneel-Grimen et al. [22], who found that general PA was less strongly associated with changes in various neighbourhood safety indicators over time than with levels of these safety indicators. This indicates that a substantial part of the safety-LTPA association is due to residential self-selection. It confirms earlier suggestions that cross-sectional studies are likely to overestimate associations of the neighbourhood environment with PA if they do not account for residential self-selection [16,17,19,].

LTPA was less strongly associated with changes in neighbourhood safety than with levels of neighbourhood safety for self-reported general safety, physical order, and social, but less so for non-victimization. This implies that self-selection is particularly evident in associations with safety perceptions, but that this may be less evident in associations with more objective safety indicators. This seems plausible as residential preferences are primarily based on people's perception of the neighbourhood.

Changes in neighbourhood safety were positively associated with both leisure-time cycling and sports, though these latter associations were only evident for some safety indicators. These results are in line with earlier research on other types of PA. Changes in neighbourhood safety have been associated with general PA [21,22] and neighbourhood walking [20]. Our results indicate that neighbourhood safety may be associated with leisure-time cycling beyond residential self-selection. The same may be true for leisure-time sports, though the evidence is somewhat weaker.

Contrary to the results for leisure-time cycling and sports, we found that changes in neighbourhood safety were negatively associated with leisure-time walking. In neighbourhoods that got safer over time, perhaps adults have substituted walking for cycling and sports, hence leading to lower levels of walking but higher levels of cycling and sports [30]. However, it remains unclear why adults would choose to substitute walking for cycling or sports.

Overall, LTPA was more consistently associated with changes in social order and non-victimization than with changes in general safety and physical order. This implies that the social neighbourhood environment may be a more important cause of fear than the physical environment. A recent review of qualitative evidence on fear of crime and the environment provides evidence to support this hypothesis [31]. Qualitative studies have identified social nuisance and crime as key sources of fear that keep adults from walking in their neighbourhood [32,33]. While physical disorder was also found to keep adults from walking, this was mainly because of aesthetical reasons, which may have a less powerful impact on PA than fear [32,33].

Changes in neighbourhood safety were generally more strongly associated with LTPA among women, older adults, and lower educated adults. These results are somewhat in line with previous research. Jongeneel-Grimen et al. [21,22] found that changes in various neighbourhood safety indicators tended to be more strongly associated with PA among women. Associations did not clearly differ by age. Humpel et al. [20] found that traffic safety changes were only positively associated with walking among women. Subgroup differences have been suggested to be the result of differences in physical and social vulnerability [12,14]. Women and elderly may be less able to defend themselves during an attack than their counterparts. Adults with a lower socio-economic status may be more exposed to unsafe situations and may have fewer resources to deal with the medical and economic consequences of victimization than their counterparts. As a result, these groups may be more inclined to restrict their LTPA when feeling unsafe.

## CONCLUSIONS

So far, evidence on the association between neighbourhood safety and LTPA has primarily been derived from cross-sectional studies that do not account for residential self-selection. Our results indicate that these studies are likely to overestimate associations of neighbourhood safety with leisure-time cycling and sports, because a substantial part of these associations may be attributable to residential self-selection, particularly when using subjective safety indicators. Longitudinal and quasi-experimental studies are needed to assess the extent to which observed associations reflect a causal effect of neighbourhood safety on LTPA.

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## CONFLICTS OF INTEREST

The authors declare that they have no competing interests.

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