TRAVEL BEHAVIOR RELATED DETERMINANTS OF MENTAL MAP QUALITY: AN EMPIRICAL STUDY

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ABSTRACT

This paper presents the results of an empirical study into mental map formation and the role of travel behavior and sociodemographic factors as determinants of mental maps. Data on stated mental map types and quality, revealed mental map quality, travel behavior and sociodemographics are collected for 576 students of Eindhoven University of Technology, and relations are examined using a variety of univariate, bivariate and multivariate analyses. A number of results are obtained. For example, our analyses support results obtained in a recent study into the role of travel mode-choice as a determinant of revealed mental map quality: traveling by means of active modes, requiring active navigation of the traveler, leads to higher quality mental maps. We find strong effects for both the car and bicycle modes (relative to using the more passive bus-mode). In addition, a range of other new findings is reported. For example, there appears to be a rather strong correspondence between stated mental map quality and actual, revealed quality. This correspondence, however, is relatively weak among men (who overestimate their mental map quality when compared to women), Architecture students (who underestimate the quality of their mental map when compared to students at other departments) and residents of Eindhoven (who underestimate the quality of their mental maps relative to non-residents).

1. INTRODUCTION

The study of mental or cognitive maps[1] has been central to the field of Human Geography and Environmental Psychology for many years (e.g. *1-4*). Recently the specific interrelations between mental map formation and travel behavior have also gained increasing attention in transportation research (e.g. *5-10*). This latter stream of research has provided much supportive evidence, both theoretical and empirical, for the claim that in order to properly understand peoples' mental map formation processes one needs to understand their travel behavior and vice versa (e.g. *11*).

For instance, it has been suggested that mental maps are an important co-determinant of accessibility: if one is unaware of a particular destination, or does not know how to reach it, the destination becomes *de facto* inaccessible (e.g. *10*, *12*). In relation to this suggestion, it is increasingly acknowledged that mental maps play an important role in shaping activity-patterns (e.g. *5*, *8*, *9*). Another example of the effect of mental maps on travel behavior is found in Horning et al. (*13*), who suggest that the perceived availability of nearby opportunities (e.g., for doing groceries) influences travelers' inclination to walk or bicycle. Dziekan (*14*) argues that the absence of an adequate mental map of a transit system potentially hampers travelers' transit ridership. This is in line with the empirical finding that regular car-drivers on average perceive their mental map of the transit system as very unreliable and inaccurate (*15*). Arentze & Timmermans (*6*) show how travelers' inclination to improve their mental map may lead them to choose routes and locations not visited before in a variety seeking-based Bayesian learning process. As a final example, a recent study shows how mental map limitations, in terms of not being aware of travel alternatives and their characteristics (e.g. travel times), heavily affects travel choice quality (*16*). In addition, it is shown how these mental map limitations lead to the acquisition of travel information among travelers (*16*, *17*).

As these examples show, the effect of mental map formation on travel choice behavior has received more attention than the role of travel choice behavior as a determinant of mental maps (*10*). This difference in attention especially holds for empirical research efforts and is somewhat surprising in light of the multitude of theoretical suggestions that travel behavior - be it in the form of, for example, route choice, destination choice, or travel information acquisition - plays a potentially very important role in helping shape travelers' mental maps (e.g. *6*, *11*, *17*).

A notable exception is found in (*10*), where it is empirically assessed to what extent travel mode-choice behavior influences quality and shape of travelers' mental maps of Los Angeles, California. The authors "find preliminary evidence that travel mode affects how individuals perceive the built environment, both in how they estimate distance and in the relative refinement of their cognitive maps". Specifically, the authors find that travelers using 'passive modes' (modes that do not require the traveler to navigate his or her way through the city themselves, such as transit) on average overestimate the distance of landmarks when compared to travelers using 'more active modes' such as the car. Also in the context of another exercise (involving picking the closer of two well known destinations), passive-travel mode users scored worse than users of active modes, and the difference was more pronounced among those residents living in LA for less than five years. As the authors conclude, travel mode choice-behavior appears to play an important role in shaping mental maps.

This paper aims to contribute to this emerging literature on the impact of travel behavior in general, and travel mode choice-behavior in specific, on mental map formation.

[1] In line with a number of earlier studies, we define a mental (or cognitive) map as a representation of spatial knowledge in the memory of human beings. Note that the word 'map' is not used here to imply or suggest that spatial knowledge is necessarily represented in the form of a 'map-like' image.

Firstly, we investigate whether the main finding of (*10*) – mental maps of users of passive travel modes are on average of less quality than those of users of active modes – can be replicated in the context of a very different population: the sample we used consists of students of Einhoven University of Technology (The Netherlands). Since both transit (a passive mode) and especially bicycle (an active mode) are popular travel modes among Dutch students, this sample complements the LA-based sample used in (*10*) where car was the dominant 'active mode'. Furthermore, the town of Eindhoven is much smaller than LA (both in terms of number of inhabitants (210,000 versus 3,850,000) as well as surface (88 squared kilometer versus 1290)), a difference that also provides a means to assess the general applicability of the findings reported in (*10*). Note that although this study was designed without knoweldge of the work presented in (*10*), both (*10*) and this paper measure mental map quality by means of a quiz about an urban area, which facilitates comparisons between the two studies.

Secondly, besides an assessment of how socio-demographic factors in combination with travel (mode-choice) behavior affect revealed, or objectively measurable, mental map quality, we also study their impact on stated, or perceived, mental map quality and type. That is, we asked respondents how they would assess their mental map of Eindhoven themselves, in terms of type and quality. These variables are related in this paper to socio-demographic factors and travel (mode-choice) behavior. Finally, we relate travelers' stated mental map type and quality with revealed mental map quality. The result is a study that builds on and contributes to recent empirical literature describing the impact of travel behavior on mental map formation.

Section 2 describes the data-collection effort and presents response group characteristics[2]. Section 3 presents the empirical analyses and Section 4 derives conclusions and points at directions for further research.

2. DATA-COLLECTION AND RESPONSE GROUP CHARACTERISTICS

2.1. Data-collection

Data were collected by means of a paper-and-pencil survey administered in October 2006. Respondents were all students of Eindhoven University of Technology, and interviewing took place at the university campus as well as at dormitories. Respondents were offered no money or other incentive for participation, as filling in the survey only took about 10 minutes. They were told upfront that the aim of the survey was to gain insight into how people form an image of Eindhoven, over the course of their studies at Eindhoven University of Technology. A total of 576 completed surveys were collected. Due to the set-up of the interviewing process, a reliable response rate could not be obtained.

2.2. Response group characteristics

Table 1 shows response group characteristics in terms of socio-demographics and some relevant travel behaviour-related factors. Of course, the sample is by no means a random or representative one, especially in terms of age and education level (all respondents were university students). Furthermore, our respondents are likely to be more captive to the transit

[2] Given the availability of a number of excellent recent literature reviews concerning both mental map formation (e.g. *13*) as well as the interrelations between mental map formation and travel behavior (e.g. *7*, *10*, *11*), we refrain from presenting a separate in-depth literature review in this paper for reasons of space limitations.

mode than the average inhabitant of Eindhoven: in The Netherlands, only a subset of students own a car, while all students are entitled to a public transport card, allowing them free travel either during weekdays or weekend-days. Finally, a large share of our respondents consists of Architecture students who are likely to differ from the average inhabitant in terms of interest in and familiarity with the concept of mental map as a representation of spatial knowledge. These response group characteristics inherently limit the general applicability of our study, which is something that should be kept in mind when interpreting our analyses and empirical findings.

Table 1: Response group characteristics

Variable	**Frequency (total = 576)**
Gender	
Male	401
Female	175
Age	
$17 < \text{age} \leq 20$	111
$20 < \text{age} \leq 25$	387
$25 < \text{age} \leq 30$	42
Study	
Architecture	331
Other	245
Residence	
Eindhoven	414
Other	162
Number of trips made within the town of Eindhoven per week[3]	
$0 < \#\text{ trips} \leq 2$	193
$3 < \#\text{ trips} \leq 5$	242
$5 < \#\text{ trips} \leq 10$	59
$10 < \#\text{ trips}$	82
Most used travel mode for these trips	
Bus	53
Car / Motorbike	30
Bicycle / Scooter	371
Walking	122

3. EMPIRICAL ANALYSES

3.1. Descriptive analysis of revealed and stated mental maps

3.1.1. Revealed mental map quality

We measured the revealed quality of respondents' mental maps in terms of answers to three quiz-questions. The first question was about positioning Eindhoven's five largest neighbourhoods on a map which only showed Eindhoven's most well known streets. Because

[3] We asked students to exclude trips made to and from the university campus.

the town of Eindhoven has over the years grown by adding distinct neighbourhoods to the municipality (in fact, these neighbourhoods used to constitute villages, largely separated from the other neighbourhoods), each of these neighbourhoods has a quite distinct character. Secondly, respondents were asked to position five landmarks[4] quite well-known to Eindhoven's inhabitants, in terms of whether the landmark was positioned 'in front of', 'behind', 'to the left of' or 'to the right of' Eindhoven's Central Railway station (when standing with one's back to the railway station, in front of the main entrance). Thirdly, respondents were asked to locate five other extraordinary buildings[5] on a map which only showed Eindhoven's main streets, the railway and the river 'De Dommel'. Figure 1 shows the true location of landmarks and gives a rough impression of Eindhoven's layout.

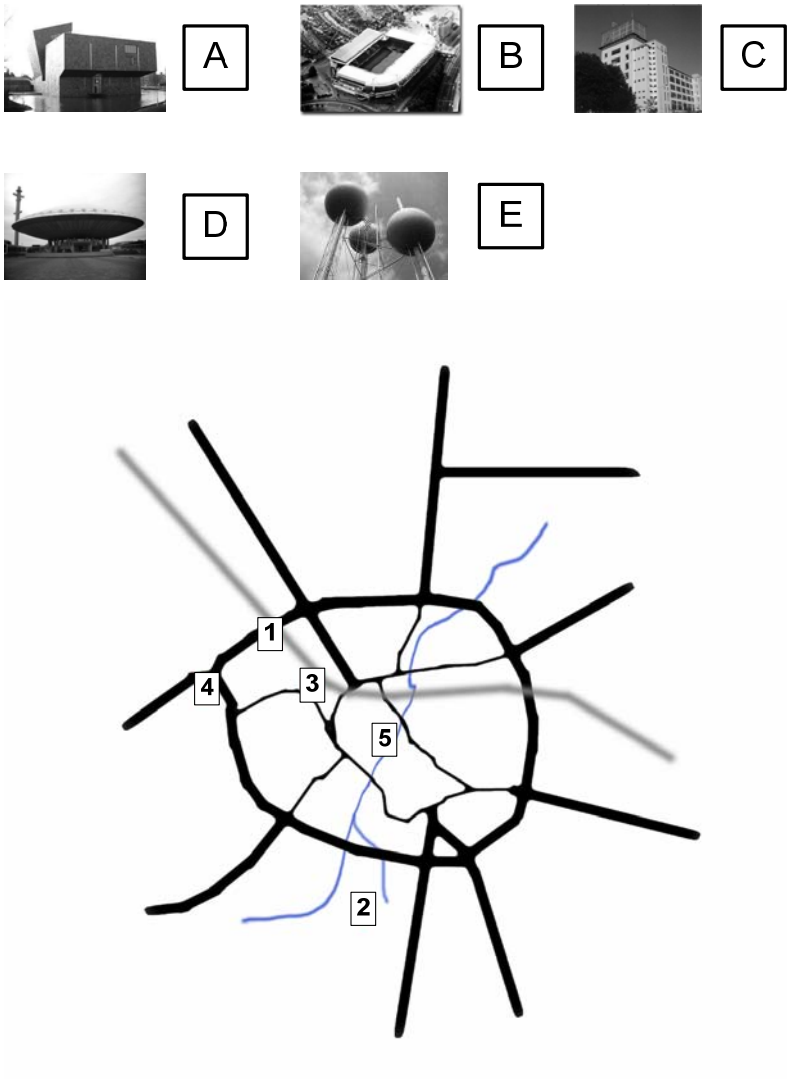

Figure 1: Question 3 of the mental map quiz – Eindhoven landmarks

In total, a maximum of 15 points could be scored on this test (5 points per question). On average, respondents scored 10.7 points (3.53 per question), with a standard deviation of 3.50. Cronbach's alpha equalled .714, and could not be improved by removing questions. This

[4] A large swimming pool, a large family hotel, a large shopping center, a performing arts facility and a theatre.
[5] The soccer stadium of PSV Eindhoven (B / 1), the former headquarters of Philips electronics (C / 3), two museum buildings (the Van Abbe-museum (A / 5) and the Evoluon (D / 4)) and a water tower (E / 2).

signals that adding together the three scores produces a fairly reliable scale. We conceive this summed score as representing the revealed (or actual) quality of a respondent's mental map.

3.1.2. Stated mental map quality

In addition to revealed mental map quality, we also asked respondents to state their perception of the quality of their mental map. Specifically, we asked them three questions: firstly, respondents were asked how good they were in wayfinding in Eindhoven. Answer categories were: 'poor' (1 point), 'reasonable' (2 points), 'good' (3) and 'very good' (4). The average score was 2.3 (standard deviation: .80), implying that the average respondent considered him- or herself as performing slightly better than reasonable in terms of wayfinding in Eindhoven. Secondly, we asked respondents to state of what percentage of Eindhoven they thought they had a fairly detailed overview. Answer categories were 'less than 25 %' (1 point), 'between 25 % and 75 %' (2 points) and 'more than 75 %' (3). The average score was 1.58 (standard deviation: .59). Thirdly, we asked respondents whether they felt that Eindhoven was 'easy to understand' in terms of its lay-out[6]. Answer categories were 'very difficult' (1 point), 'difficult' (2 points), 'not easy, not difficult' (3), 'easy' (4 points) and 'very easy' (5). The average score was 3.10 (standard deviation: .81), implying that respondents conceive Eindhoven's layout as being moderately difficult.

As we felt that the three questions were likely to relate to different aspects of stated mental map-quality, we chose not to add them together in a composite scale, but treat them as separate measurements of stated mental map quality in the remainder of this paper.

3.1.3. Stated mental map type

Finally, we asked respondents to answer the following question, to identify their stated mental map type: "When forming a picture of Eindhoven in terms of its spatial structure, what comes to mind first?". Answer categories were (answer frequency percentages between brackets, rounded total = 100 %): 'a kind of map' (45 %), 'one or more routes I usually take' (27 %), 'one or more extraordinary buildings or structures' (15 %), 'particular streets or open spaces (squares)' (8 %), 'particular parks' (0 %), 'something else' (1 %) and 'nothing in particular' (3 %). It appears that the majority of stated mental maps are conceived in terms of a map or (a set of) route(s).

3.2. Relations between revealed and stated mental maps

We begin by analyzing the relation between on the one hand stated mental map type, and on the other hand stated and revealed mental map quality. As discussed above, a variety of mental map-types was identified, and respondents stated what type they felt was applicable to their mental map. Importantly, note here that questions about stated mental map type and quality preceeded the quiz questions aiming at revealing actual mental map quality, to avoid a situation where participants' perceived performance on the quiz affected their perceived mental map type and quality.

When relating stated mental map type and stated mental quality, the following relations were found: respondents whose stated mental map was 'a kind of map' scored relatively high on stated mental map quality. Specifically, their answers to the question how good they were in wayfinding in Eindhoven averaged 2.36 while respondents who reported

[6] Note that answers to this question not necessarily relate to one's perceived mental map quality. We will treat this variable as an indirect measure of perceived mental map quality in the remainder of this paper.

another mental map type scored an average of 2.25 (p-value: .099). Their score on the question whether they felt that Eindhoven was easy to understand in terms of its lay-out averaged 3.21 while respondents who reported another mental map type scored an average of 3.01 (p-value: .003). No significant difference was found with respect to the question of what percentage of Eindhoven they thought they had a fairly detailed overview. Other distinctions in terms of stated mental map type did not result in significant differences in terms of stated mental map quality.

When relating stated mental map type with revealed mental map quality (i.e.: the summed score on the three quiz questions presented above), it is found that respondents whose stated mental map took the form of 'a kind of map' scored significantly higher in terms of revealed mental map quality than those with other mental map types: 11.30 versus 10.17, p-value: .000).

We proceed by analyzing the relations between the different measurements of stated mental map quality, and between stated and revealed mental map quality. Table 2 presents correlations (non-parametric Spearman-correlations) between the three measurements of stated mental map quality and the summed quiz score conceived as revealed mental map quality. Significance levels (in terms of *p*-values) are given between brackets.

Table 2: Correlations between stated and revealed mental map quality [7]

Correlations	Stated wayfinding	Stated overview	Stated easy lay-out	Revealed quality
Stated wayfinding	1	-	-	-
Stated overview	.640 (.000)	1	-	-
Stated easy lay-out	.172 (.000)	.166 (.000)	1	-
Revealed quality	.544 (.000)	.481 (.000)	.107 (.010)	1

Two of the three identified measurements of stated mental map quality correlate very positively (and very significantly) with each other and with revealed mental map quality: respondents that consider themselves good wayfinders (in Eindhoven) and state that they have a good overview of the town, score higher on the three quiz questions. Correlations are less pronounced with respect to the variable 'stated easy lay-out'. This is not so surprising, as whether Eindhoven is perceived to be easily understood in terms of its lay-out or not, probably says more about the town's lay-out than about the stated and revealed mental map quality of its inhabitants. However, also here found correlations are significant. In sum, these correlations show that on average, respondents have a fairly accurate assessment of their mental map quality: stated quality corresponds rather well with revealed quality.

When comparing different categories of respondents in terms of this correspondence, some interesting findings emerge. Firstly, it appears that women are more accurate in assessing their mental map quality than men (correlations between stated and revealed mental map quality are stronger for women than for men). While reporting about equal in terms of

[7] 'Stated wayfinding' refers to the question about wayfinding in Eindhoven. 'Stated overview' refers to the question of what percentage of Eindhoven respondents thought they had a fairly detailed overview. 'Stated easy lay-out' refers to the question whether respondents felt that Eindhoven was easy to understand in terms of its lay-out. 'Revealed quality' refers to the summed answers to the three quiz questions.

stated mental quality, women score slightly higher than men in terms of revealed quality. For reasons of space limitations, we refrain from providing correlations, differences in terms of correlations, and significance levels here. Secondly, it appears that students of the Department of Architecture are less accurate in assessing their mental map quality than students from other departments. They state lower quality-levels than other students, but in fact their actual mental map quality is higher: architecture students appear to be too conservative in terms of assessing their mental map quality. Finally, residents of Eindhoven also appear to be too modest in terms of assessing their mental map quality: stated mental map quality is slightly higher than for non-residents, but the difference in terms of revealed mental map quality is much larger (in favour of residents' revealed mental map quality).

3.3. Determinants of stated and revealed mental maps

We identify the determinants of stated mental map types, and stated and revealed mental map quality, by means of performing a series of linear and logistic regressions. Independent variables are listed in Table 3.

Table 3: Independent variables

Variable	Description
Gender	0 = female, 1 = male
Year_birth	Year of birth
Department	0 = other, 1 = Architecture
Resident	0 = no resident of Eindhoven, 1 = resident of Eindhoven
Resident_long	Number of years residing in Eindhoven (0 = no resident)
Inspect_map	1 = I never have inspected a map of Eindhoven 2 = I haven't inspected a map of Eindhoven recently 3 = I inspect a map of Eindhoven every now and then 4 = I inspect a map of Eindhoven on a regular basis
Number_trips	Number of trips made within the town of Eindhoven per week[8]
Duration_trips	Average duration of these trips
Car_trip[9]	I mostly take the car for these trips
Bicycle_trip	I mostly take the bicycle for these trips
Walk_trip	I mostly walk these trips

[8] We asked students to exclude trips made to and from the university campus.
[9] Taking the bus (a passive travel mode) serves as a base-case. Car, bike and walking serve as dummy-variables.

In terms of expected effects of these independents and stated and revealed mental map quality, we expect positive relations (if any) for all variables except year of birth and gender. Concerning year of birth, we expect negative effects, and we have no particular ex ante expectations concerning the effect of gender. Note that the expectation of positive effects of the use of active travel modes (car, bicycle, walking) on revealed mental map quality is based on earlier work on this topic (*10*). We have less strong *a priori* expectations regarding the effects of the listed independents on stated mental map type, although perhaps it may be expected that men will be more likely to conceive Eindhoven as 'a kind of map' than women, and that people who inspect maps of Eindhoven on a regular basis are relatively prone to conceive the town as 'a kind of map' as well. In addition, it may be expected that users of active travel modes are more prone to have the 'a kind of map' type of mental map.

3.3.1. Determinants of stated mental map type

To start with the latter, we regress stated mental map type ('a kind of map' (1) versus other stated mental map types (0)) on the listed independents, using binary logistic. Positive (negative) parameter estimates imply that a high score on the independent variable increases (decreases) the likelihood that stated mental map type is 'a kind of map'. Table 4 shows the estimation results, leaving out the estimated constant.

Table 4: Determinants of stated mental map type 'a kind of map'

Variable	**B**	**SE**	**p-value**
Gender	.533	.201	.008
Year_birth	-.014	.040	.722
Department	.124	.185	.501
Resident	-.085	.279	.760
Resident_long	-.022	.575	.448
Inspect_map	.326	.111	.003
Number_trips	-.010	.019	.589
Duration_trips	-.009	.010	.360
Car_trip	-.292	.532	.583
Bicycle_trip	.641	.348	.065
Walk_trip	-.232	.377	.538
Nagelkerke R-square		*.085*	

The only significant relations refer to variables Gender, Inspect_map and Bicycle_trip (significant only at the 90 % level): men appear to more inclined than women to perceived Eindhoven in terms of 'a kind of map', as was expected. Also as expected, inspecting a map of Eindhoven induces people to conceive a map-like mental map of the town as well. Finally, respondents that mostly travel by bicycle are more inclined than bus-users to conceive a map-like mental map of Eindhoven. The model's low Nagelkerke R-square signals that, in addition to the variables discussed here, stated mental map type is co-determined by a multitude of other factors not considered here.

3.3.2. Determinants of stated mental map quality

We go on to regress stated mental map quality on the listed independents, using linear regression. Positive (negative) parameter estimates imply that a high score on the independent variable increases (decreases) the respondent's perception of his or her mental map quality, measured in terms of the independents 'wayfinding', 'overview' and 'easy lay-out' (see above for full descriptions of these variables). Table 5 shows the estimation results, leaving out the estimated constants.

Table 5: Determinants of stated mental map quality

	Wayfinding			**Overview**			**Easy lay-out**		
Variable	**B**	**SE**	**p-value**	**B**	**SE**	**p-value**	**B**	**SE**	**p-value**
Gender	.069	.067	.301	.037	.050	.465	.003	.078	.970
Year_birth	-.039	.013	.004	-.035	.010	.001	-.008	.016	.624
Department	-.031	.062	.621	-.074	.047	.114	-.105	.072	.148
Resident	-.029	.093	.756	-.076	.071	.286	-.088	.109	.418
Resident_long	.060	.010	.000	.039	.007	.000	-.026	.011	.020
Inspect_map	-.009	.037	.809	-.005	.028	.846	.103	.043	.017
Number_trips	.024	.006	.000	.019	.005	.000	.011	.007	.147
Duration_trips	-.001	.003	.686	-.002	.002	.465	.003	.004	.447
Car_trip	.325	.171	.058	.316	.129	.015	.520	.199	.009
Bicycle_trip	.321	.117	.006	.185	.088	.035	.196	.135	.148
Walk_trip	.086	.125	.494	.000	.095	.998	.075	.146	.607
R-square		*.216*			*.201*			*.041*	

A number of relevant results can be found in this Table: firstly, it appears that gender has no effect on stated mental map quality, when controlling for all other independents. Secondly, year of birth has a negative effect (or: age has a positive effect) on stated mental map quality that is significant for both 'wayfinding' and 'overview' measures. Because we have controlled for the number of years a person lives in Eindhoven, existence of this separate effect implies that people tend to perceive the quality of their mental maps as higher when they grow older.

When controlling for the other variables, Architecture students appear to have slightly lower stated mental map quality than other students, although the effects are insignificant at conventional levels. Living in Eindhoven has no effect on stated mental map quality, although the amount of years residing in Eindhoven does: the longer one lives in Eindhoven, the higher one scores on variables 'wayfinding' and 'overview', as expected. However, the effect on 'easy lay-out' is negative and significant, which signals that Eindhoven's lay-out in fact becomes perceived as more and more difficult over the years. This is another sign of the distinguished nature of this measurement: again, it seems that the independent variable says more about Eindhoven's lay out, than it does about the stated mental map quality of its inhabitants. Inspecting a map on a regular basis does appear to help people understand Eindhoven's lay-out, as the effect is positive and significant. As was expected, people who travel often have more faith in their mental maps than do people that travel less. The duration of these trips does not seem to have an effect, the number of trips made is key here.

In terms of the effect of travel mode-choice on stated mental map quality, it appears that, as expected and in line with previous work[10] (*10*), use of active modes (in the sense that the traveller is required to navigate through the city him- or herself) has a positive effect on stated mental map quality, when compared to using the passive mode (bus). The effects are significant for car and bicycle (somewhat surprisingly, not for walking), and are strongest for the car-mode.

The models' reasonable, but certainly not overwhelmingly high, R-squares signal that, although the variables discussed here seem to play an important role in determining stated mental map quality, a multitude of other factors is important as well. In line with our previous discussions, R-square of the 'wayfinding' and 'overview' models is much higher than that of the 'easy lay-out' model.

3.3.3. Determinants of revealed mental map quality

Finally, we regress revealed mental map quality (conceived as the sum of the three quiz-questions) on the same independents that entered the models of stated mental map type and quality above. Table 6 provides the estimation results. The constant is omitted.

As was the case with stated mental map quality, gender does not seem to play a role in terms of revealed quality. Age is not a relevant factor, too. Note that age does have a positive effect on stated mental map quality: this implies that the older people get, the more they tend to overestimate, or the less they tend to underestimate, their mental map quality (note again that we controlled for the number of years living in Eindhoven). Students at the Department of Architecture appear to have slightly more accurate mental maps than do students of other departments (however, their stated mental map quality does not differ significantly from that of other students, as was discussed earlier).

Although being a residence has no additional effect on stated mental map quality (controlling for the number of years one lives in Eindhoven), it does have an additional and positive effect in terms of revealed mental map quality. Simply living in town apparently

[10] Although (*10*) was concerned with revealed, not stated, mental map quality in the terminology of this paper.

helps forming a mental map of relatively high quality, also when living there only since very recently. However, the effect is only significant at the 90 % level. More substantial, and highly significant, is the positive effect of the number of years living in Eindhoven, on the revealed quality of one's mental map of Eindhoven. Inspecting a map, although beneficial in the sense that one gets the feeling that one better understands Eindhoven's lay-out, does not increase revealed mental map quality. It is more effective to go out and make actual trips, as is implied by the estimated positive and significant coefficient. Again, the duration of trips made does not seem to play a role.

Table 6: Determinants of revealed mental map quality

Variable	**B**	**SE**	**p-value**
Gender	-.069	.297	.815
Year_birth	-.062	.060	.302
Department	.774	.276	.005
Resident	.717	.415	.085
Resident_long	.222	.043	.000
Inspect_map	.040	.164	.808
Number_trips	.066	.028	.021
Duration_trips	.010	.014	.489
Car_trip	1.914	.760	.012
Bicycle_trip	1.287	.516	.013
Walk_trip	-.110	.556	.844
R-square		*.202*	

We conclude by discussing the effect of travel mode-choice on revealed mental map quality. In line with earlier hypotheses and empirical findings (*10*), we see that using active modes, i.e. modes that require active navigation by the traveller, significantly helps increasing the quality of mental maps. Travelling by car or bicycle, as opposed to travelling by bus (a more passive mode), has a very substantial, positive effect on revealed mental map quality. Interestingly, as was the case in the three models of stated mental map quality, the effect of walking (compared to riding the bus) on revealed mental map quality is by no means significant.

4. CONCLUSIONS AND DISCUSSION

This paper presents the results of an empirical study into mental map formation and the role of travel behaviour and sociodemographic factors as determinants of mental maps. We distinguish between stated mental map types (how does someone describe his or her mental map?), stated mental map quality (how good does someone think that his or her mental map is?) and revealed mental map quality (how good is someone's mental map?). Data on stated mental map types and quality, revealed mental map quality, travel behaviour and sociodemographics are collected for 576 students of Eindhoven University of Technology, and relations are examined using a variety of univariate, bivariate and multivariate analyses. A number of interesting results are obtained.

Firstly, our analyses support the hypotheses and results obtained in a recent study (*10*) into the role of travel mode-choice as a determinant of revealed mental map quality: travelling by means of active modes, requiring active navigation of the traveller, leads to higher mental map quality. We find strong effects for both the car and bicycle modes (relative to using the more passive bus-mode), but, somewhat surprisingly, we find no significant effects for walking. Possibly, walking distances are rather small, which prohibits the formation of accurate mental maps of larger areas, such as the municipality of Eindhoven. We further contribute to this recent literature by also examining the effect of using active modes on stated mental maps: we find that using active modes increases one's perception of the quality of one's mental map, and that bicycle use in particular leads to a higher inclination to conceive ones environment like an actual map (as opposed to, for example, having a mental map dominated by landmarks). Again, walking does not lead to significantly better of different stated mental maps than riding the bus.

In addition, a range of other new findings is reported. For example, there appears to be a rather strong correspondence between stated mental map quality and actual, revealed quality. This correspondence, however, is relatively weak among men (who overestimate their mental map quality when compared to women), Architecture students (who underestimate their mental map when compared to students at other departments) and residents of Eindhoven (who underestimate their mental maps relative to non-residents).

Furthermore, people tend to believe that their mental maps become better over time, but this is not supported by actual mental map quality improvements, when controlling for the number of years someone lives in Eindhoven. Stated mental map quality also improves with the number of years one lives in Eindhoven, a finding that is supported by actual improvements in mental map quality. Inspecting a map on a regular basis does not appear to help in improving revealed mental map quality, although it does make one believe that the city is relatively easy to navigate. Making trips substantially improves both stated and revealed mental map quality, also when controlling for the type of mode used (passive versus active). The duration of these trips is unimportant: it is the number of trips that counts.

At this point, we wish to stress again that the analysis described in this paper are based on a sample that is neither random nor representative for the average inhabitant of Eindhoven. Although it is not directly clear how our results would change when analyzing a more representative sample, clearly, collecting and analyzing such a random sample constitutes an important avenue for further research. However, the fact that our results are in line with those obtained from a survey that was administered in another part of the world, and included a large share of non-students, does provide some additional validity to our findings.

If these findings can be generalized, they have some practical implications in a variety of application domains. First, many transport planning policies, such as for example those related to accessibility and social exclusion, are often based on "objective" measures, using information about land use distribution and the transportation network. However, the

relationship between the physical world and behaviour is mediated through a cognitive environment. As evidenced by the present study, the relationship between the physical and the cognitive environment is nonlinear, implying that an analysis of mental maps should be beneficial in developing local planning schemes. Secondly, for urban planners and designers, the findings of this study emphasize the importance of the congruence between urban form and the transportation network, not only in terms of navigation but also in terms of supporting local markets.

As our findings support earlier work on the influence of travel behaviour (and travel mode-choices in particular) on mental map formation, another fruitful avenue for further research is to incorporate mental map-models, more explicitly than what is currently done, in operational models of activity-travel behaviour, especially if the model is developed for a particular city. Mental maps not only introduce bias in estimated travel times, they also dictate awareness of alternatives and hence choice sets. Current practice of arbitrarily defining choice sets on the basis of revealed behaviour is not only ad hoc, but also ill-founded. The inclusion of mental maps will obviously create some additional model complexity, but it is becoming more and more clear that ignoring mental maps in travel behaviour research means ignoring an important aspect of behaviour. This holds for cross-sectional data, but is increasingly more relevant for the development of dynamic activity-based models.

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