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**The Pedestrian Behaviour Scale: A systematic review of its validation around  
the world**

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19 **Abstract**

20 **Objective:** The Pedestrian Behaviour Scale (PBS) is a self-report questionnaire that  
21 distinguishes five dimensions of pedestrian behaviour: violations, errors, lapses, aggressive  
22 behaviours and positive behaviours. This study aimed to meet three objectives: to trace the  
23 development of the PBS worldwide from 1997 to 2021, to report on its varied uses and to  
24 analyze the scientific validation of the different dimensions of pedestrian behaviour reflected  
25 by the PBS and its derivatives.

26 **Design/methodology:** In this systematic literature review, we selected all works that cited the  
27 2013 founding study of the PBS as well as all publications that cited the frequently replicated  
28 2017 validation of the PBS in America. We conducted an online database search using Web of  
29 Science, Google Scholar, ResearchGate and PubMed. After excluding duplicates, 116 studies  
30 were identified. A total of 30 studies were selected to meet our first two objectives and 14  
31 studies were selected to meet our third objective.

32 **Results:** Over time, the PBS has undergone many changes. Overall, we found differences in  
33 the scientific validation of this questionnaire depending on the version used, the validation  
34 tests performed and the population studied. The original version of the PBS and its Turkish  
35 adaptation proved most appropriate for assessing the transgressions dimension. The  
36 American version of the PBS proved a suitable alternative but it is more suited to assessing  
37 the two independent dimensions of violations and errors. The Chinese version of the PBS  
38 proved unsuitable for assessing the lapses dimension, while the original version of the PBS  
39 emerged as the best option for assessing aggressive behaviours. The positive behaviour  
40 dimension presented many validation difficulties.

41 **Conclusion:** As no systematic review of the PBS has been conducted before, researchers can  
42 now make an informed choice of methodology quickly and be guided by our  
43 recommendations regarding the use and possible improvements of the different validated  
44 versions.

45 **Keywords:** Systematic Review, Pedestrian Behaviour Scale, Validation, Pedestrian Behaviour,  
46 Survey

## 47 **1.1. Introduction**

48 Despite progress in road safety, the number of road deaths worldwide remains high, with an  
49 estimated 1.35 million deaths reported in 2016 (WHO, 2018). More than half of road deaths  
50 involve more vulnerable road users, such as pedestrians. Road traffic crashes involving  
51 pedestrians appear to be unevenly distributed worldwide. For example, pedestrian deaths for  
52 2016 were estimated at 40% of road deaths in the African region and 14% in the Southeast  
53 Asian region (WHO, 2018). There are also significant differences in other world regions. In  
54 Europe, the percentage of pedestrian deaths in 2016 as a proportion of all road casualties was  
55 estimated at 1% in Norway and 37% in Romania (European Commission, 2018).

56 Overall, progress in road safety policies has mainly benefitted motorists, while pedestrian  
57 accidents have stagnated. The study of pedestrian behaviour could therefore help to reduce  
58 road deaths by adopting protective measures and policies specific to this mode of road use.  
59 Self-reported risk behaviour has been found to correlate with observed behaviour in other  
60 safety domains, such as driver behaviour (West et al., 1993) and involvement in car accidents  
61 (Hatakka et al., 1997). To date, studies of pedestrian behaviour have focussed on the effects  
62 of sociodemographic, environmental and social variables. These studies have largely been  
63 based on self-report questionnaires derived from driver behaviour studies. Reason et al.  
64 (1990) constructed the Driver Behaviour Questionnaire (DBQ), a 50-item questionnaire  
65 dedicated to drivers that made it possible to investigate the frequency of various road  
66 behaviours in a self-reported manner. This questionnaire broke down driver behaviour into  
67 three dimensions: violations, errors and lapses. Violations were described as deliberate  
68 offences that posed a definite risk to other road users (e.g. not observing speed limits late at  
69 night), errors as dangerous mistakes (e.g. not noticing a pedestrian crossing) and lapses as

70 'stupid' rather than dangerous mistakes (e.g. forgetting where the car was parked). Parker et  
71 al. (1995) confirmed these three dimensions of driving behaviour in a much larger sample.  
72 Lawton et al. (1997) introduced an affective dimension to driver behaviour: aggressive  
73 behaviours. This dimension was confirmed in several studies, notably in Turkey (Sümer &  
74 Özkan, 2002; Lajunen & Özkan, 2004). Another dimension, positive behaviour, was posited by  
75 Özkan and Lajunen (2005). They designed a new questionnaire, the Positive Driver Behaviour  
76 Scale, which investigated positive driving behaviours such as caring for the road environment  
77 and other road users and helping and being polite with or without safety concerns.

## 78 **1.2. Literature review**

79 The study of driver behaviour has greatly contributed to the development of instruments to  
80 investigate pedestrian behaviour. Moyano-Diaz (1997) developed a questionnaire based on  
81 the DBQ (Moyano-Diaz, 1997) called the Scale of Pedestrian Behaviour. This scale broke down  
82 pedestrian behaviour into the same three dimensions used to study driver behaviour:  
83 violations, errors and lapses. The author found that men reported more violations than  
84 women, with no difference in the reporting of errors and lapses between the two sexes.  
85 Subsequently, Yildirim (2007) used 17 items from the scale developed by Moyano-Diaz to  
86 study the relationship between religiousness, conservatism, locus of control and the traffic  
87 behaviour of both drivers and pedestrians. His factor analyses revealed three dimensions of  
88 pedestrian behaviour: errors (e.g. almost got hit by a car as a result of not checking whether  
89 the road was clear), 'ordinary' violations (e.g. crossed the road when the pedestrian light was  
90 red) and 'aggressive' violations (e.g. got angry with and gesticulated at another road user).  
91 Despite an internal consistency at the limit of the acceptability threshold as measured by  
92 Cronbach's alpha of 0.70 (Cicchetti, 1994; DeVon et al., 2007) for the 'ordinary violation'

93 factor, this study distinguished a new dimension, aggressive pedestrian behaviour. Torquato  
 94 and Bianchi (2010) also used Moyano-Diaz’s pedestrian behaviour scale to study pedestrian  
 95 behaviour in Brazil.

96 To better understand pedestrian behaviour, Granié et al. (2013) developed and validated a  
 97 self-report scale to measure injury risk behaviours in pedestrians of all ages, known as the  
 98 Pedestrian Behaviour Scale (PBS). The PBS was based on six validated questionnaires:  
 99 Moyano-Diaz’s (1997) pedestrian behaviour scale, the Driver Behaviour Questionnaire (DBQ)  
 100 (Reason et al., 1990), Lawton et al.’s (1997) aggressive driver behaviours scale; the Positive  
 101 Driver Behaviours Scale (Özkan & Lajunen, 2005), the Adolescent Road User Behaviour  
 102 Questionnaire (ARBQ) (Elliott & Baughan, 2004), and Granié’s road user behaviour perception  
 103 scale (Granié, 2008). The PBS consisted of 40 items and seven filter questions. For each item,  
 104 participants have to answer the following question: ‘As a pedestrian, how often do you  
 105 perform the following behaviours?’ In terms of these questionnaires, pedestrian behaviour  
 106 was approached from five dimensions: violations, errors, lapses, aggressive behaviours and  
 107 positive behaviours (Table 1).

<b>Pedestrian Behaviour</b>	<b>Definition</b>	<b>Example</b>	<b>Reference</b>
<b>Violation</b>	Deliberate deviation from social rules without intention to cause injury or damage.	Not using nearby pedestrian crosswalk to cross	Reason et al. (1990)
<b>Error</b>	Deficiency in knowledge of traffic rules and/or in the inferential processes involved in making a decision.	Crossing diagonally to save time	Rasmussen (1980), Reason et al. (1990)
<b>Lapse</b>	Unintentional deviation from practices related to a lack of concentration on the task; forgetfulness.	Forgetting to look around for vehicles before crossing	Reason et al. (1990)
<b>Aggressive Behaviour</b>	A tendency to misinterpret other road users’ behaviour resulting in the intention to annoy or endanger.	Getting angry with another user and insulting him	Lawton et al. (1997), Baxter et al. (1990)

<b>Positive Behaviour</b>	Behaviour that seeks to avoid violation or error and/or seeks to ensure traffic rule compliance.	Not crossing diagonally or letting other road users go first	Özkan and Lajunen (2005)
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108

109 Table 1: Definitions of different types of pedestrian behaviours. Source: Deb, Strawdermann,  
110 DuBien et al. (2017).

111 However, using principal component analysis (PCA), Granié et al. (2013) distinguished only  
112 four dimensions for pedestrian behaviour: transgressions, lapses, aggressive behaviours and  
113 positive behaviours. This study also led to the construction of a shorter scale (23 items) by  
114 selecting the four most saturated items from each dimension. After it was validated in France  
115 (Granié et al., 2013), the PBS has been used and extended in several countries around the  
116 world. Some researchers have added items from the PBS to other questionnaires. In Spain,  
117 Herrero-Fernández (2015) pooled the transgressions dimension with items from the ARBQ  
118 (Elliott & Baughan, 2004) to create the Cuestionario de Riesgo en Peatones (CRP), a short self-  
119 report questionnaire for pedestrian risk behaviours. This questionnaire was also used in a pilot  
120 study to develop and validate a self-report questionnaire to measure anger in pedestrians  
121 (Herrero-Fernández et al., 2019). In Turkey, Demir et al. (2019) used the transgression  
122 dimension to compare explanatory models of pedestrian behaviour. Other authors were  
123 inspired by this questionnaire, without using it as such. To establish different pedestrian  
124 profiles, Papadimitriou, Lassarre, and Yannis (2016) included items from the PBS into a set of  
125 questionnaires (on perceptions, attitudes, beliefs and motivations) that were used in a series  
126 of field observations in Athens, Greece. From this study, three pedestrian profiles emerged:  
127 risk takers and optimizers, conservatives and public transport users, and pedestrians for  
128 pleasure. This questionnaire was also used in related studies (Papadimitriou, 2016;  
129 Papadimitriou et al., 2017). Jalilian et al. (2014) used seven items from the PBS related to  
130 transgressions and lapses to examine the effect of mobile phone and personal music device



131 usage on crossing behaviours among Iranian medical students. Similarly, Nesoff et al. (2019)  
132 used the PBS to understand how the public perceived pedestrian safety to help develop  
133 prevention strategies. Finally, the PBS was adapted to investigate the main factors influencing  
134 cyclists' crossing intentions when interacting with an automated vehicle compared to a  
135 conventional vehicle (Velasco et al., 2021).

136 The aim of this systematic review was to bring together all the knowledge in the literature on  
137 pedestrian behaviour questionnaires in a rigorous and comprehensive scientific manner. To  
138 do this, we chose to work with studies that used the full PBS or one of its derivatives. This  
139 protocol allowed us to identify, collect, review and synthesise relevant studies to obtain the  
140 current state of knowledge on the assessment of pedestrian behaviour by questionnaire. By  
141 also drawing on the grey literature, this methodology limits the introduction of random and  
142 systematic errors or biases. Thus, our study establishes a common base of knowledge on the  
143 pedestrian behaviour questionnaire that is useful and accessible to both experienced  
144 researchers in the research topic and young researchers. Our study will allow them to make  
145 better decisions by evaluating the different versions before making their methodological  
146 choices while reducing the time required to read each individual study. They will be able to  
147 choose a version based on its history and previous uses. The second objective of this review  
148 was to observe and analyse the limitations of the questionnaires in terms of validation or study  
149 population and to propose solutions to these shortcomings in future iterations of the  
150 questionnaire. In this study, we identify promising versions of the questionnaire and those  
151 requiring further investigation. Through our proposed solutions and the identification of  
152 future research, researchers will be able to replicate this questionnaire in their geographical  
153 area, while addressing its validation difficulties. In this way, pedestrian behaviour and all its  
154 dimensions will have the opportunity to be measured, analysed and understood. Road safety

155 interventions can then be tailored to the results of this questionnaire and have a greater  
156 impact on the pedestrian mortality rate.

157 In the first part of this paper, we list all the studies that used the PBS or one of its derivative  
158 versions to reflect the evolution of this questionnaire over the years and across cultures. In  
159 the second part of our paper, we present an overview of the different uses of the PBS and its  
160 derivative versions. Finally, we analyze and validate the dimensions of pedestrian behaviour  
161 related to the different validated versions of the PBS.

## 162 **2 Method**

### 163 2.1 Eligibility criteria and search strategy

164 The systematic review methodology described in the PRISMA framework (Page et al., 2020)  
165 was used in this study. We selected all studies that cited the original study on the PBS by  
166 Granié et al. (2013). Indeed, all studies citing it were regarded as potentially relevant for this  
167 systematic review. We also included the study by Deb, Strawdermann, DuBien et al. (2017)  
168 because their US-validated version was replicated many times without citing the seminal  
169 article. We began by identifying scientific articles to trace the history of the tool and its  
170 different uses (see 3.1 and 3.2). For these two sections, we selected studies that used a full  
171 version of the PBS or one of its derivatives using the following inclusion criteria: 1) the study  
172 had to be published in a peer-reviewed journal, and 2) the study had to use at least 15 items  
173 from one of the validated versions of the questionnaire. To examine the validation of the  
174 different tools and the dimensions covered (see 3.3), we subjected the selected studies to a  
175 third inclusion criterion: the version used in the selected study had to have been validated by  
176 means of a factor analysis and an internal consistency assessment.

### 177 2.2 Data elements and synthesis methods

178 Studies that used at least 15 items from a modified version of the PBS were included in the  
179 validation section (see 3.3). Each study was required to have performed factor analysis (such  
180 as PCA, exploratory factor analysis or confirmatory factor analysis) as well as an internal  
181 consistency assessment using Cronbach's alpha. These results have not been reported in a  
182 previous study. Each collected result is recorded in the tables in the validation section (see  
183 3.3) of this study. No other variables were investigated.

### 184 2.3 Sources of information

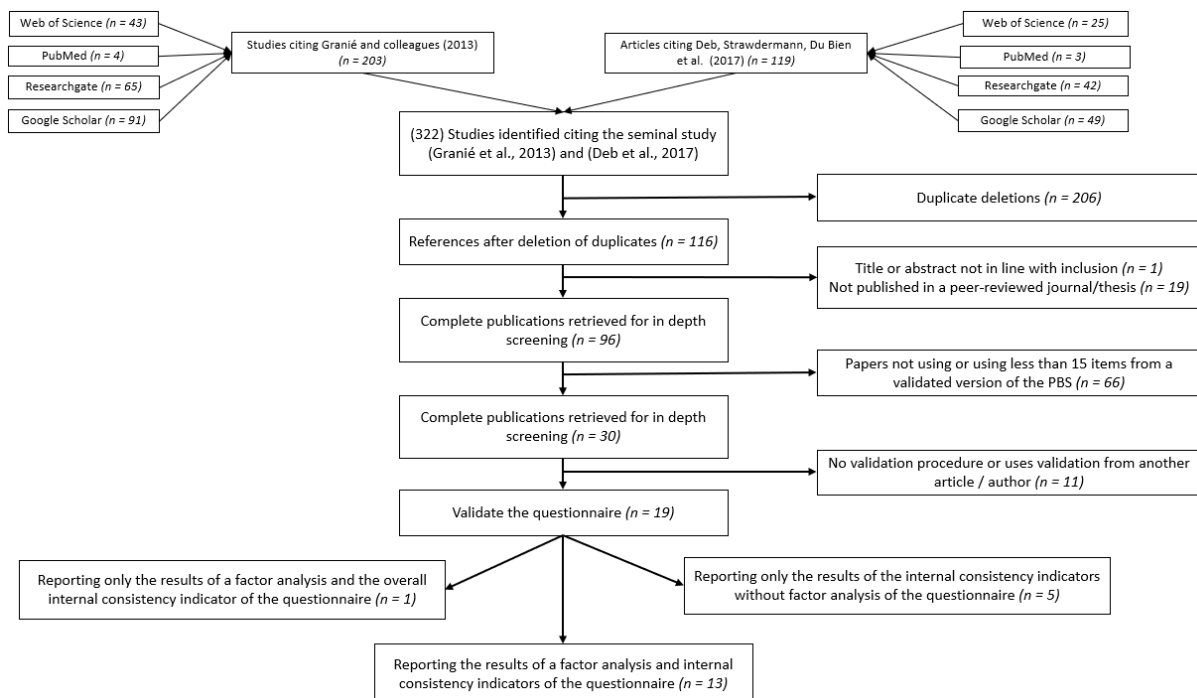
185 To identify relevant studies, we searched online search engines using Web of Science, Google  
186 Scholar, ResearchGate and PubMed. Searches were conducted during April 2021. The use of  
187 databases and scientific collaboration networks in systematic reviews is well established and  
188 ensures that grey literature is included (Facchinetti et al., 2019; Hajjej et al., 2019; Amiri &  
189 Behnezhad, 2020).

### 190 2.4 Data selection and collection process

191 The selection of studies was done exclusively by the lead author. Each study was recorded in  
192 a summary table that all authors had access to that presented the publication review, the  
193 study sample, the version of the questionnaire used, the number of items used and the scale  
194 validation proposals and tests. The application of these criteria reduced the number of studies  
195 from 322 to 14 (see Figure 1). The search process in the different databases identified 322  
196 publications: 203 studies that cited Granié et al. (2013) and 119 studies that cited Deb,  
197 Strawdermann, DuBien et al. (2017). After eliminating duplicates ( $n = 206$ ), 116 publications  
198 were reviewed to assess the research area and the journal of publication. After this step, 96  
199 studies were examined in more detail to assess whether they used a version of the PBS and,  
200 if so, how many items were reused in their study. A total of 66 studies did not use a validated

201 version of the PBS or used less than 15 items. The remaining 30 were further screened  
 202 regarding the evolution and uses of the questionnaire (see 3.1 and 3.2). We further  
 203 investigated the validation or otherwise of the questionnaire used. A total of 11 studies did  
 204 not present any information regarding the validation of the questionnaire or used a previous  
 205 study's validation. We then examined the validation procedures of the remaining 19 studies;  
 206 one reported only the factor analysis results and the overall internal consistency of the  
 207 questionnaire, and five reported the internal consistency indicators without having performed  
 208 a factor analysis. The remaining 13 studies thus constituted our questionnaire validation  
 209 section (see 3.3).

210



211

212 Figure 1. Flow chart for study collection

213 **3 Results**

214 3.1 The full story of the PBS

215 3.1.1 The evolution of the PBS and its different versions

216 The PBS has been replicated several times. A global overview in the form of a summary graph  
217 (Figure A.) is presented in Appendix. Following its initial validation by Granié et al. (2013),  
218 Nordfjærn and Şimşekoğlu (2013) used it to investigate the role of cultural variables and  
219 attitudes toward safety on the self-reported risky pedestrian behaviour of urban pedestrians  
220 in Turkey. They retained only those items from the PBS dimensions that addressed  
221 transgressions, lapses and aggressive behaviours. They added 10 items from their own field  
222 observations of pedestrian behaviour. They found that pedestrian behaviour could be divided  
223 into three dimensions with their version: transgressions (deliberate violations of a series of  
224 pedestrian safety regulations and norms), attention violations (items relating to violations  
225 committed by pedestrians due to failures caused by a number of internal or external stimuli)  
226 and aggressive behaviours (two items relating to aggressive behaviour of pedestrians towards  
227 other users of the road traffic system). Şimşekoğlu (2015) also used this version of the PBS to  
228 investigate the role of attitudes and personality traits on Turkish pedestrian behaviour. The  
229 PBS validated in Nordfjærn and Şimşekoğlu's (2013) study was reused in the Eastern  
230 Mediterranean region, where Nordfjærn and Zavareh (2016) examined differences in  
231 pedestrian safety attitudes, pedestrian risk behaviours and cultural dimensions in samples of  
232 young adults (18-25 years) from Iran and Pakistan. It was used again in Turkey (Serin et al.,  
233 2018) to examine the relationship between pedestrian safety attitudes and pedestrian  
234 behaviours, without specific validation of the PBS.

235 Following Nordfjærn and Şimşekoğlu's 2013 study, the original PBS was replicated in some  
236 European countries as well as in Iran. With the aim of intervening in pedestrian behaviour, 32  
237 items of the PBS were used in Esfahan, Iran (Jalilian, Darani et al., 2015). This experimental  
238 study demonstrated the effectiveness of an email intervention on safe crossing behaviours in  
239 a population of medical science university students.

240 In 2016, the PBS was modified and validated in Serbia (Antić et al., 2016) and China (Qu et al.,  
241 2016). Antić et al. (2016) used the PBS with the full set of assessed dimensions to determine  
242 the frequency of risky pedestrian traffic behaviour. They added items concerning the use of  
243 mobile phones in the context of road use. The final 20-item questionnaire explained 66.4% of  
244 the total variance and showed the importance of the reason for walking and the daily distance  
245 walked on pedestrian behaviour. They found that people who walked out of necessity  
246 committed more violations, whereas people who walked for pleasure reported a greater  
247 number of lapses. They also showed that people who walked short distances were more prone  
248 to lapses, while people who walked longer distances made more mistakes but reported more  
249 positive behaviour. Qu et al. (2016) used the PBS with all its dimensions as well as the items  
250 added by Nordfjærn and Şimşekoğlu (2013) to develop a Chinese version of the PBS (CPBS).  
251 They also adapted some items to the Chinese population. Using this version, they tested the  
252 relationship between pedestrian behaviours, daily life experiences and personality traits. The  
253 CPBS was reused frequently for the study of pedestrian behaviour in China. For example,  
254 Zheng et al. (2017) used it to investigate the effects of personality traits and global perceived  
255 stress on pedestrian behaviour. Subsequently, Xu, Liu et al. (2018) examined the validity of  
256 the CPBS among a sample of 625 drivers and non-drivers and compared the pedestrian  
257 behaviour of the two samples. The CPBS was used in another study in China to examine the  
258 relationships between pedestrians' perceived inconvenience in urban traffic, road safety  
259 climate and pedestrian behaviour (Xu, Ge et al., 2018). The CPBS was used in 2020 to explore  
260 the relationship between parental absence and pedestrian behaviour of primary school  
261 children (Meng et al., 2020).

262 In the United States, Deb, Strawdermann, DuBien et al. (2017) used the original 43-item PBS  
263 to develop and validate the Pedestrian Behavior Questionnaire (PBQ) for the US population.

264 The scale was only slightly modified: American English rather than British English was used  
 265 and applied to the American transportation system. The authors did not delete or add items.  
 266 After factorial analysis, Deb et al. created a new short version consisting of 20 items. It is also  
 267 interesting to see that in their study, Deb and her colleagues took the opportunity to analyse  
 268 six possible alternative models to explain pedestrian behaviour (see Table 2). The four-factor  
 269 model (model 2) corresponds to the analysis of pedestrian behaviour by Granié et al. (2013),  
 270 the three-factor model (model 3) to that of Papadimitriou et al. The five-factor model (model  
 271 4) corresponds to the factor analysis of pedestrian behaviour in the study by Deb,  
 272 Strawdermann, DuBien et al. The table presented shows us that the five-factor model (model  
 273 4) has the best CFI and PCFI with the lowest RMSEA compared to the other models presented  
 274 and validated in France and Greece, and good factor loadings. The strong independence found  
 275 between the dimensions except for positive behaviours then led Deb and colleagues (2017) to  
 276 assume that there was a second-order underlying factor for the four factors, called "risky  
 277 behaviours". This second-order factor was then tested and compared in model 5 and 6. Model  
 278 6 showed a better fit with good and statistically significant factor loadings. Finally, Model 4  
 279 and Model 6 showed a better fit, and this categorisation of the analysis dimensions seemed  
 280 to be the most relevant for studying pedestrian behaviour. According to these analyses, 4 or  
 281 5 dimensions would have to be found within pedestrian behaviour for the study to be valid.  
 282 These elements lead us to question the validity of studies identifying a number of less than 4  
 283 factors such as Nordfjærn & Şimşekoğlu's (2013) study and the replications of their  
 284 questionnaire.

Models	$\chi^2$	df	$\chi^2 / df$	Absolute Fit RMSEA	Comparative Fit CFI	Parsimonious Fit PCFI
Model 1: One factor, pedestrian behavior	2747.44	623	4.410	0.09	0.737	0.69

<b>Model 2:</b> Transgressions (violations & errors), lapses, aggressive behaviors, and positive behaviors	1622.85	617	2.630	0.07	0.85	0.78
<b>Model 3:</b> Risk-taking and optimization (violations, errors, lapses, and aggressive behaviors), conservative (positive behaviors), and pedestrian for pleasures	3387.74	893	3.794	0.08	0.715	0.68
<b>Model 4:</b> Five factors (violations, errors, lapses, aggressive behaviors, and positive behaviors)	1528.79	613	2.494	0.06	0.89	0.82
<b>Model 5:</b> Second-order, two first-order factors: risky behaviors (violations, errors, lapses, and aggressive behaviors), and positive behaviors	1528.79	616	2.568	0.07	0.86	0.80
<b>Model 6:</b> Second-order (pedestrian behavior), five first-order factors: violations, errors, lapses, aggressive behaviors, and positive behaviors	1349.84	581	2.323	0.06	0.90	0.83

285 Table 2: Alternatives for the best first-order confirmatory factor model.

286 The short questionnaire validated by Deb, Strawdermann, DuBien et al. (2017) was widely  
287 used in subsequent years in the Americas region (Deb, Strawdermann, Carruth et al., 2017;  
288 2018; Ruiz et al., 2020). Deb reused her questionnaire with US participants to validate a  
289 pedestrian reactivity to FAVs (fully automated vehicles) questionnaire (PRQF) (Deb,  
290 Strawdermann, Carruth et al., 2017) and to study the influence on pedestrian crossing  
291 behaviour (Deb et al., 2018). The short questionnaire of Deb, Strawdermann, DuBien et al.  
292 (2017) was used by Ruiz et al. (2020) to validate it on a Mexican population.

293 The PBQ has been replicated in different regions of the world, including the United Kingdom,  
294 Africa (Kenya), Southeast Asia (Bangladesh, Thailand), and the Western Pacific (China,  
295 Vietnam) (McIlroy, Plant et al., 2019; McIlroy, Kokwaro et al. 2020; McIlroy, Nam et al., 2020;  
296 Dinh et al., 2020a, 2020b; Liu et al., 2021). McIlroy, Plant et al. (2019) used the 20-item PBQ  
297 with slight modifications to test the factor structure and validate the short version of a  
298 pedestrian behaviour questionnaire in six culturally and economically distinct countries,  
299 Bangladesh, China, Kenya, Thailand, the United Kingdom and Vietnam. McIlroy, Kokwaro et  
300 al. (2020) compared the responses to this questionnaire with different variables such as



301 fatalistic beliefs and general attitudes toward road safety in different countries. The extensive  
302 data collected in this study has resulted in numerous studies that investigated the effect of  
303 socio-demographic variables, fatalistic beliefs and attitudes toward road safety (Dinh et al.,  
304 2020b; McIlroy, Kokwaro et al., 2020) as well as road risk perception (Dinh et al., 2020b;  
305 McIlroy, Nam et al., 2020b) on pedestrian behaviour. Dinh et al. (2020a) reused data from the  
306 Viet Nam-specific study by McIlroy, Plant et al. (2019) and investigated the role of fatalistic  
307 beliefs about road safety attitudes on pedestrian behaviour. Very recently, Liu et al. (2021)  
308 reused data pertaining to China from McIlroy, Plant et al. (2019) to examine the effects of  
309 attitudes toward road safety, fatalistic beliefs, and risk perceptions on self-reported  
310 pedestrian behaviour in a Chinese sample.

### 311 3.1.2 The first version of the PBS as a milestone

312 Since 2018, the original PBS has been used in a number of countries throughout the world  
313 (Hungary, Romania, the Netherlands, Estonia, Greece, Kosovo, Russia, Turkey, New Zealand,  
314 Iran). Hógye-Nagy (2018) used the full 43-item PBS to present as the basis for the Hungarian  
315 adaptation of the scale and to assess the most important characteristics of pedestrian traffic  
316 in Hungary. Chraif (2019) used the shortened PBS in Romania to investigate whether  
317 personality traits predicted positive pedestrian behaviour. It was used in the Netherlands  
318 (Velasco et al., 2019) to examine the effect of the physical appearance of an automated vehicle  
319 and an external human-machine interface (eHMI) on pedestrians' intention to cross, as well  
320 as to assess the perceived realism of virtual reality based on 360° videos for pedestrian  
321 crossing behaviour for research purposes. Solmazer et al. (2020) replicated the PBS in five  
322 European countries: Estonia, Greece, Kosovo, Russia and Turkey. This study showed that there  
323 were many differences in pedestrian behaviour within the same continent. In New Zealand,

324 Larue and Watling (2021) used the PBS to examine the intention-actual behaviour link and  
325 applied the technology acceptance model (TAM) to distracted pedestrian interventions. These  
326 authors also used it to study the effects of in-ground LED lights at railway crossings to attract  
327 the attention of pedestrians who are distracted by their smartphones (Larue, Watling, Black,  
328 & Wood, 2021). The PBS was also used in a laboratory study on the effect of flashing LEDs on  
329 the attention of distracted pedestrians in Australia and New Zealand (Larue, Watling, Black,  
330 Wood, & Khakzar, 2020). Esmaili et al. (2021) used 41 items from the PBS to validate this  
331 questionnaire in a sample of Persian pedestrians in Iran and to examine the relationship  
332 between these behaviours and demographic and mobility variables. Finally, O’Hern et al.  
333 (2020) built on previous international versions of pedestrian behaviour questionnaires to  
334 validate a questionnaire for a cohort of Australians. This study is interesting in the history of  
335 the development of pedestrian behaviour scales because the PBS by Moyano-Diaz (2002), the  
336 PBS by Granié et al. (2013), the PBS by Nordfjærn and Şimşekoğlu (2013), Antić’s (2016)  
337 version of the PBS, the CPBS by Qu et al. (2016) and the scale by Deb Strawdermann, DuBien  
338 et al. (2017) were reconciled into one questionnaire. The authors also added the distraction  
339 scale by Young et al. (2019). The original 128-item questionnaire was reduced by factor  
340 analysis, and the authors defined four dimensions with sufficient internal consistency for  
341 pedestrian behaviour: deliberate violations, unintentional errors, aggressive behaviours, and  
342 engagement with technology.

### 343 3.2 PBS used to investigate many variables

344 The PBS is a multipurpose tool that has been used to examine pedestrian behaviour through  
345 individual variables, questionnaires, and different protocols. In this section, we present an  
346 overview of the different uses to which this instrument has been put in the past.

347 This tool has been used to assess pedestrian behaviour, but also to link the different  
348 dimensions of pedestrian behaviour to many individual variables (see table A.1. in the  
349 supplementary material). Thus, in addition to basic socio-demographic data such as gender,  
350 age and education level, some studies have linked PBS to broader socio-demographic variables  
351 showing that income and marital status (Esmaili et al., 2021) would be related to pedestrian  
352 behaviour. However, subjective socio-economic status (Dinh et al., 2020a) or having a child  
353 (Esmaili et al., 2021) are elements that would not impact pedestrian behaviour. Pedestrian  
354 behaviour as assessed by the PBS or one of its versions was also related to several variables  
355 concerning the road environment, such as infrastructure, mobility and previous crash  
356 involvement. Pedestrian behaviour was found to be related to the level of satisfaction with  
357 the infrastructure and the environment (Nordfjærn & Şimşekoğlu, 2013; Şimşekoğlu, 2015)  
358 but also to the mode of transport such as cycling or public transport (Hőgye-Nagy, 2018).  
359 Pedestrian behaviour is also strongly related to driver behaviour (Şimşekoğlu, 2015): we can  
360 see the impact of frequency (Granié et al., 2013) and daily time spent driving (Hőgye-Nagy,  
361 2018; Esmaili et al., 2021) on pedestrian behaviour. Some elements related to the walking  
362 context also play a role in pedestrian behaviour such as reasons for walking (Hőgye-Nagy,  
363 2018; Antić et al., 2016) as well as frequency, walking time or distance walked (Granié et al.,  
364 2013; Antić et al., 2016; Esmaili et al., 2021). Finally, other studies have shown that pedestrian  
365 behaviour would be impacted by previous involvement in an accident, whether as a  
366 pedestrian (Esmaili et al., 2021; Deb et al., 2017), as a driver (Esmaili et al., 2021) or as a road  
367 user (Granié et al., 2013; McIlroy et al., 2019; Ruiz et al., 2020).

368 Studies that have linked the PBS or one of its versions with other validated questionnaires  
369 have shown us the links between pedestrian behaviour and multiple variables such as  
370 attitudes, risk perception, cognitive processes, and numerous psychological variables (see

371 Table A.2. in the supplementary material). The link between dimensions of pedestrian  
372 behaviour and attitudes towards road users (Serin et al., 2018) or towards road safety  
373 (Nordfjærn & Şimşekoğlu, 2013; Şimşekoğlu, 2015; Nordfjærn & Zavareh, 2016; McIllroy et al.,  
374 2020a; 2020b; Dinh et al., 2020a; 2020b; Liu et al., 2021) have been found repeatedly. Other  
375 studies show links between pedestrian behaviour with several elements related to the road  
376 context such as pedestrian annoyance (Xu, Ge et al., 2018), traffic climate (Xu, Ge et al., 2018),  
377 driver behaviour (Şimşekoğlu, 2015) or receptivity to fully autonomous vehicles (Deb,  
378 Strawderman, Carruth et al., 2017; Deb et al., 2018). The links between pedestrian behaviour  
379 and risk perception in the road context have been more difficult to highlight. Overall, risk  
380 perception on the road would not be a variable completely related to pedestrian behaviour  
381 (Liu et al., 2021). In looking further into this variable, Dinh et al. (2020b) showed us that  
382 although the perception of general risks associated with the use of motor vehicles or the  
383 perception of risks associated with vulnerable road users does not have an impact on  
384 pedestrian behaviour, the perception of the risks of traffic accidents is an element to be  
385 considered. They also told us that there is a link between the perception of food and health  
386 risks and pedestrian behaviour. Pedestrian behaviour was also studied in terms of  
387 psychological variables. Thus, many studies show us the role of personality-related elements  
388 on pedestrian behaviour (Şimşekoğlu, 2015; Qu et al., 2016; Chraif, 2019; Zheng et al., 2017),  
389 but also stress (Zheng et al., 2017) and self-control in children (Meng et al., 2020). Cognitive  
390 processes related to attention are also mentioned as potentially impacting pedestrian  
391 behaviour (Qu et al., 2016; Xu, Liu et al., 2018). Finally, more broadly, we can see the role of  
392 values (Solmazer et al., 2020), collectivist and individualist tendencies (Nordfjærn &  
393 Şimşekoğlu, 2013; Nordfjærn & Zavareh, 2016) and fatalistic beliefs (McIllroy, Kokwaro et al.,  
394 2020; Dinh et al., 2020a; Liu et al., 2021) on different dimensions of pedestrian behaviour.

395 This questionnaire has also been used with different protocols (see Table A.3. in the  
396 supplementary material) such as scenario-based questions (Deb Strawdermann, DuBien et al.,  
397 2017), pedestrian simulators (Deb et al., 2018), eye-tracking systems (Larue & Watling, 2021;  
398 Larue, Watling, Black, & Wood, 2021) and virtual reality (Deb et al., 2018; Velasco et al., 2019).

399 Given the large number of uses of the PBS, its adaptation to different populations and the  
400 plurality of its uses (understanding behaviour through economic, technological, psychological  
401 and cultural dimensions, profiling, control of laboratory studies, interventions), it is clear that  
402 the PBS is a tool that has deepened scientific knowledge of pedestrian behaviour for many  
403 years. However, in-depth studies of pedestrian behaviour can only be carried out using a  
404 questionnaire adapted to the population under study. It is important to have a global view of  
405 the validation of a questionnaire to obtain an objective view before choosing an appropriate  
406 research methodology for the study population. To this end, in the following review, we focus  
407 more specifically on studies that have used and validated the PBS and its replications. We have  
408 listed all validated versions of the PBS in the countries where it has been used. We have seen  
409 that the validation of certain dimensions depends strongly on the version used. Therefore, we  
410 present our results regarding the current limitations and propose solutions and a framework  
411 for using this questionnaire for future researchers wishing to use it to study pedestrian  
412 behaviour.

### 413 3.3 Validation of the different dimensions of pedestrian behaviour across the world

414 The validation results of the selected studies are presented in terms of the dimensions of  
415 pedestrian behaviour and are reported according to the different countries and regions of the  
416 world classified by the WHO. The 13 selected studies as well as the founding study by Granié  
417 et al. (2013) are also presented according to the versions used (Granié et al., 2013; Nordfjærn

418 & Şimşekoğlu, 2013; Qu et al., 2016; Deb Strawdermann, DuBien et al., 2017). The validation  
419 tests carried out to classify each item by dimension are available in the supplementary  
420 material (see Table B). PCA was used to list each item on the dimension(s) to which it best  
421 corresponded. Exploratory factor analysis (EFA) was used to check the number of factors to  
422 which the various items corresponded. Confirmatory factor analysis (CFA) was used to confirm  
423 whether the items corresponded to the various dimensions sought. As factor analyses depend  
424 on the researchers' objective (explore vs. confirm), it is important to consider this element for  
425 the overall analysis of the validation of the different versions of the questionnaire. We see  
426 that the validation of the questionnaires is done by PCA in most studies (Granié et al., 2013;  
427 Nordfjærn & Şimşekoğlu, 2013; Nordfjærn & Zavareh, 2016; Qu et al., 2016; Solmazer et al.,  
428 2020; Dinh et al., 2020b; O'Hern et al., 2020; Esmaili et al., 2021; Liu et al., 2021). Validation  
429 studies by CFA (Deb, Strawdermann, DuBien et al., 2017; Xu et al., 2018; McIlroy et al., 2019;  
430 Ruiz et al., 2020) or by EFA (Hőgye-Nagy, 2018; O'Hern et al., 2020) are less common.

### 431 3.3.1 Transgression, violations and errors

432 Regarding risk behaviours, Granié et al. (2013) proposed differentiating between violations,  
433 which are intentional, and errors, which are unintentional; each has different psychological  
434 origins and remediation modes (Reason et al., 1990). However, in the first factor analysis to  
435 test a five-factor structure differentiating violations from errors, Granié et al. (2013) combined  
436 these two dimensions into a single independent dimension, 'transgressions'. Granié et al.'s  
437 (2013) study was not the only one to find a dimension encompassing violations and errors. Of  
438 all the studies that aimed to validate the PBS using either the short or long version of Granié  
439 et al. (2013), the common dimension of transgression was reported in Europe, the Eastern  
440 Mediterranean and the Americas, regardless of the factor analysis tests used. It was found

441 using PCA on both the short version (Solmazer et al., 2020) and the long version (Esmaili & al.,  
442 2021), and by using EFA on the short version (Hógye-Nagy, 2018). The version of the PBS used  
443 by Solmazer et al. in different European countries was modified. It included only 15 items,  
444 including five items on the transgression dimension. The Hógye-Nagy version was also  
445 modified and included only 18 items in total. The use of PCA with Nordfjærn and Şimşekoğlu's  
446 (2013) 17-item version of the PBS in Turkey and the Eastern Mediterranean found the  
447 transgressions dimension (Nordfjærn & Şimşekoğlu, 2013; Nordfjærn & Zavareh, 2016). It was  
448 found with the 18-item CPBS version in China by using PCA (Qu et al., 2016) and CFA (Xu, Liu  
449 et al., 2018). This dimension was found with the PBQ version only in Vietnam using PCA (Dinh  
450 et al., 2020b). Finally, O'Hern et al. (2020) found a transgressions-like dimension that they  
451 named 'deliberate violations'. The validation of the transgressions dimension is presented in  
452 Table 3.

TRANSGRESSIONS DIMENSION					
Country	Year	Number of participants	Internal consistency	Questionnaire	Authors
European Region					
France	2013	343	$\alpha = 0.89$	PBS Long version (Granié et al., 2013)	Granié et al. (2013)
Turkey		289	$\alpha = 0.866$	PBS (Nordfjærn et al., 2013)	Nordfjærn & Şimşekoğlu (2013)
Hungary	2018	526	$\alpha = 0.807$	PBS short version * (Granié et al., 2013)	Hógye-Nagy (2018)
Greece	2020	249	$\alpha = 0.82$	PBS short version * (Granié et al., 2013)	Solmazer et al. (2020)
Turkey		145	$\alpha = 0.79$		
Kosovo		112	$\alpha = 0.75$		
Estonia		131	$\alpha = 0.78$		
Russia		176	$\alpha = 0.85$		
Eastern Mediterranean Region					
Pakistan	2016	161	$\alpha = 0.763$	PBS (Nordfjærn et al., 2013)	Nordfjærn & Zavareh (2016)
Iran		131	$\alpha = 0.811$		
	2021	520	$\alpha = 0.79$	PBS Long version (Granié et al., 2013)	Esmaili et al. (2021)
Western Pacific Region					
China	2016	283	$\alpha = 0.72$	CPBS (Qu et al., 2016)	Qu et al. (2016)
	2018	625	$\alpha^1 = 0.61$		Xu, Liu et al. (2018)

$\alpha^2 = 0.61$					
Vietnam	2020	835	$\alpha = 0.82$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Dinh et al. (2020b)
Australia		968	$\alpha = 0.88$	32 items* (O'Hern et al., 2020)	O'Hern et al. (2020)

453

454 **Table 3: Validation table of the transgressions dimension by world region (WHO).** The symbol  $\alpha^1$  in the  
 455 study by Xu, Liu et al. (2018) represents the driver sample and  $\alpha^2$  represents the non-driver sample. The symbol  
 456 \* represents the versions modified by the authors before the questionnaire was released.

457 The transgressions dimension overall shows very good internal consistency scores in the  
 458 different global regions studied with the different versions used. Only the CBPS (Qu et al.,  
 459 2016) does not show sufficient internal consistency indicators (Xu, Liu et al., 2018a).

460 The two independent dimensions of violations and errors are also found in the literature using  
 461 the PBS or the PBQ, the details of which are presented in Table 4. and those of the error  
 462 dimensions are presented in Table 3. Specifically, these two independent dimensions were  
 463 only found once with the PBS after CFA. In contrast, the PBQ version differentiated its two  
 464 dimensions in many global regions after CFA (Deb, Strawdermann, DuBien et al., 2017;  
 465 Mcllroy, Plant et al., 2019; Ruiz et al., 2020) and after PCA (Liu et al., 2021).

466 The PBS was then adapted for an American population (Deb Strawdermann, DuBien et al.,  
 467 2017). The PBQ showed satisfactory internal consistency in the African, American and Western  
 468 Pacific regions (Mcllroy, Plant et al., 2019; Liu et al., 2021) but not in the European and  
 469 Southeast Asian regions (Mcllroy, Plant et al., 2019).

VIOLATIONS DIMENSION					
Country	Year	Number of participants	Internal consistency	Questionnaire	Authors
European Region					
United Kingdom	2019	695	$\alpha = 0.591$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
African Region					
Kenya	2019	544	$\alpha = 0.715$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)



Region of the Americas					
United States	2017	425	$\alpha = 0.89$	PBS Long version (Granié et al., 2013)	Deb, Strawdermann, DuBien et al. (2017)
Mexico	2020	730	$\alpha = 0.72$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Ruiz et al. (2020).
Southeast Asian Region					
Bangladesh	2020	532	$\alpha = 0.545$	PBQ	Mcllroy, Plant et al. (2019)
Thailand		317	$\alpha = 0.690$	(Deb, Strawdermann, DuBien et al., 2017)	
Western Pacific Region					
China	2020	544	$\alpha = 0.812$	PBQ	Mcllroy, Plant et al. (2019)
Vietnam		835	$\alpha = 0.716$	(Deb, Strawdermann, DuBien et al., 2017)	
China	2021	543	$\alpha = 0.81$		Liu et al. (2021)

470 **Table 4: Validation table for the dimension of violations by world regions (WHO).** The symbol \*  
471 represents the versions modified by the authors before the questionnaire was released.

472 Regarding the errors dimension (Table 5), the long version of the PBS adapted well to the  
473 population of United States by showing interesting internal consistency indicators (Deb,  
474 Strawdermann, DuBien et al., 2017). The PBQ remained usable for European regions such as  
475 the UK and for the Southeast Asian regions (Mcllroy, Plant et al., 2019), but it did not show  
476 satisfactory indicators of internal consistency in the African region (Mcllroy, Plant et al., 2019),  
477 the Americas region (Ruiz et al., 2020) and the Western Pacific region (Mcllroy, Plant et al.,  
478 2019; Liu et al.,2021).

479

ERRORS DIMENSION					
Country	Year	Number of participants	Internal consistency	Questionnaire	Authors
European Region					
United Kingdom	2019	695	$\alpha = 0.841$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
African Region					
Kenya	2019	544	$\alpha = 0.543$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
Region of the Americas					
United States	2017	425	$\alpha = 0.83$	PBS Long version (Granié et al., 2013)	Deb, Strawdermann, DuBien et al. (2017)
Mexico	2020	730	$\alpha = 0.65$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Ruiz et al. (2020)
Southeast Asian Region					

Bangladesh	2019	532	$\alpha = 0.482$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
Thailand		317	$\alpha = 0.515$		
Western Pacific Region					
Vietnam	2019	835	$\alpha = 0.642$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
China		544	$\alpha = 0.681$		
	2021	543	$\alpha = 0.68$		Liu et al. (2021)

480 **Table 5: Validation table of the errors dimension by world regions (WHO).** The symbol \* represents the  
481 versions modified by the authors before the questionnaire was released.

482

### 483 3.3.2 Lapses

484 Details regarding the validation of the lapses dimension are presented in Table 6. This  
485 dimension is called ‘attention violations’ in the study by Nordfjærn and Şimşekoğlu (2013). It  
486 combines items from the lapses dimension (e.g. ‘I realize that I have crossed several streets  
487 and intersections without paying attention to traffic’) as well as the errors dimension (e.g. ‘I  
488 cross even if vehicles are coming because I think they will stop for me’) of the PBS. This  
489 dimension also contains items added from their own observations referring to situations on  
490 the road with the use of technology (e.g. ‘When I cross the road using a cell phone, I forget to  
491 look properly’) or when the individual has been drinking alcohol (e.g. ‘When I have been  
492 drinking alcohol, I am less likely to use pedestrian crossings’). In their factor analysis, O’Hern  
493 et al. (2020) found a dimension similar to lapses, which the authors called ‘unintentional  
494 errors’. Using Granié et al.’s (2013) long, short, or modified versions of the PBS, Nordfjærn and  
495 Şimşekoğlu’s (2013) PBS version, as well as the PBQ, the items seem to match satisfactorily  
496 with the totality of the studied world regions. However, there was a lack of internal  
497 consistency regarding this dimension in China (Qu et al., 2016; Xu, Liu et al., 2018), especially  
498 with the use of the CPBS (Qu et al., 2016).

LAPSES DIMENSION					
Country	Year	Number of participants	Internal consistency	Questionnaire	Authors
European Region					

France	2013	343	$\alpha = 0.83$	PBS Long version (Granié et al., 2013)	Granié et al. (2013)
Turkey		289	$\alpha = 0.857$	PBS (Nordfjærn et al., 2013)	Nordfjærn & Şimşekoğlu (2013)
Hungary	2018	526	$\alpha = 0.771$	PBS short version * (Granié et al., 2013)	Hőgye-Nagy (2018)
United Kingdom	2019	695	$\alpha = 0.867$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
Greece	2020	249	$\alpha = 0.91$	PBS short version * (Granié et al., 2013)	Solmazer et al. (2020)
Turkey		145	$\alpha = 0.90$		
Kosovo		112	$\alpha = 0.86$		
Estonia		131	$\alpha = 0.83$		
Russia		176	$\alpha = 0.93$		
Eastern Mediterranean Region					
Pakistan	2016	161	$\alpha = 0.746$	PBS (Nordfjærn et al., 2013)	Nordfjærn & Zavareh (2016)
Iran	2021	520	$\alpha = 0.81$		
African Region					
Kenya	2019	544	$\alpha = 0.835$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy & al. (2019)
Region of the Americas					
United States	2017	425	$\alpha = 0.90$	PBS Long version (Granié et al., 2013)	Deb, Strawdermann, DuBien et al. (2017)
Mexico		730	$\alpha = 0.77$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Ruiz et al. (2020)
Southeast Asian Region					
Bangladesh	2019	532	$\alpha = 0.843$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
Thailand		317	$\alpha = 0.842$		
Western Pacific Region					
China	2016	283	$\alpha = 0.61$	CPBS (Qu et al., 2016)	Qu et al. (2016)
	2018	625	$\alpha^1 = 0.38$ $\alpha^2 = 0.40$	CPBS (Qu & al., 2016)	Xu, Liu et al. (2018)
	2019	544	$\alpha = 0.863$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
Vietnam	2020	835	$\alpha = 0.838$		
Australia	2020	968	$\alpha = 0.87$	32 items* (O'Hern et al., 2020)	O'Hern & al. (2020)
China	2021	543	$\alpha = 0.86$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Liu et al. (2021)

499 **Table 6: Validation table of the lapses dimension by world regions (WHO).** The symbol  $\alpha^1$  in the study by  
500 Xu, Liu et al. (2018) represents the driver sample and  $\alpha^2$  represents the non-driver sample. The symbol \* represents the  
501 versions modified by the authors before the questionnaire is released.

502

503 3.3.3 Aggressive behaviours

504 Details regarding the validation of the aggressive behaviours dimension are presented in Table  
505 7. In this regard, the long version of the PBS has sufficient internal consistency in the European  
506 region (Granié et al., 2013), the Eastern Mediterranean region (Esmaili et al., 2021) and the  
507 Americas region (Deb, Strawdermann, DuBien et al., 2017). The modified short versions were  
508 successful in assessing aggressive pedestrian behaviour in the European region. The modified  
509 short version by Solmazer et al. (2020) showed sufficient internal consistency with a three-  
510 point assessment and the PBS version modified by Hőgye-Nagy (2018) showed sufficient  
511 internal consistency to assess it. Nordfjærn and Şimşekoğlu's (2013) PBS assesses the  
512 dimension of aggressive behaviour in the first validation study in the European region, but this  
513 dimension did not show sufficient internal consistency in the Eastern Mediterranean region  
514 (Nordfjærn & Zavareh, 2016). Thus, the use of the PBS might be better suited to this region  
515 (Esmaili et al., 2021). The CPBS also had difficulty assessing aggressive pedestrian behaviours,  
516 with sufficient internal consistency found for the driving population rather than the non-  
517 driving population (Xu, Liu et al., 2018a). While the PBQ worked well for assessing aggressive  
518 pedestrian behaviour in the Western Pacific region (McIlroy, Plant et al., 2019; Dinh et al.,  
519 2020b; Liu et al., 2021), the European region (McIlroy, Plant et al., 2019) and the Americas  
520 region (Ruiz et al., 2020), this was not the case in the African or the Southeast Asian regions  
521 (McIlroy, Plant et al., 2019). We note that O'Hern et al. (2020), having assembled all the  
522 versions, found this dimension independently of aggressive behaviour.

AGGRESSIVE BEHAVIOURS DIMENSION					
Country	Year	Number of participants	Internal consistency	Questionnaire	Authors
European Region					
France	2013	343	$\alpha = 0.70$	PBS long version (Granié et al., 2013)	Granié et al, (2013)
Turkey		289	$\alpha = 0.837$	PBS (Nordfjærn et al., 2013)	Nordfjærn & Şimşekoğlu (2013)

Hungary	2018	526	$\alpha = 0.636$	PBS short version * (Granié et al., 2013)	Hógye-Nagy (2018)
United Kingdom	2019	695	$\alpha = 0.766$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
Greece	2020	249	$\alpha = 0.86$	PBS short version * (Granié et al., 2013)	Solmazer et al. (2020)
Turkey		145	$\alpha = 0.86$		
Kosovo		112	$\alpha = 0.90$		
Estonia		131	$\alpha = 0.78$		
Russia		176	$\alpha = 0.91 (+1$ Lapses et 1PB)		
Eastern Mediterranean Region					
Pakistan	2016	161	$\alpha = 0.657$	PBS (Nordfjærn et al., 2013)	Nordfjærn et Zavareh (2016)
Iran		131	$\alpha = 0.674$		
		2021	520		
African Region					
Kenya	2019	544	$\alpha = 0.675$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
Region of the Americas					
United States	2017	425	$\alpha = 0.88$	PBS long version (Granié et al., 2013)	Deb, Strawdermann, DuBien et al. (2017)
Mexico	2020	730	$\alpha = 0.73$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Ruiz et al. (2020)
Southeast Asian Region					
Bangladesh	2019	532	$\alpha = 0.687$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
Thailand		317	$\alpha = 0.778$		
Western Pacific Region					
China	2016	283	$\alpha = 0.64$	CPBS (Qu et al., 2016)	Qu et al. (2016)
	2018	625	$\alpha^1 = 0.71$ $\alpha^2 = 0.68$	CPBS (Qu et al., 2016)	Xu, Liu et al. (2018)
	2019	544	$\alpha = 0.887$	PBQ	Mcllroy, Plant et al. (2019)
Vietnam	2020	835	$\alpha = 0.858$	(Deb, Strawdermann, DuBien et al., 2017)	Dinh et al. (2020b)
	2020	835	$\alpha = 0.86$		
Australia	2020	968	$\alpha = 0.86$	32 items* (O'Hern et al., 2020)	O'Hern et al. (2020)
China	2021	543	$\alpha = 0.89$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Liu et al. (2021)

523 **Table 7: Validation table of the aggressive behaviours dimension by world regions (WHO).** The symbol  
524  $\alpha^1$  in the study by Xu, Liu et al. (2018) represents the driver sample and  $\alpha^2$  represents the non-driver sample.  
525 The symbol \* represents the versions modified by the authors before the questionnaire was released.

526

### 527 3.3.4 Positive behaviours

528 All the versions selected had difficulty validating the positive behaviours dimension (Table 8).

529 The original PBS did not include this dimension because of a lack of internal consistency. Only

530 the modified version by Solmazer et al. (2020) had good internal validity, but only in one of  
 531 the five European countries studied. Nordfjærn and Şimşekoğlu (2013) did not assess this  
 532 dimension. The PBQ also failed to assess this dimension because of a lack of internal  
 533 consistency except in Mexico (Ruiz et al., 2020). The CPBS was successful in assessing this  
 534 dimension in a Chinese population, except in a non-driver population (Xu, Liu et al., 2018a).

535

POSITIVE BEHAVIOURS DIMENSION					
Country	Year	Number of participants	Internal consistency	Questionnaire	Authors
European Region					
France	2013	343	$\alpha = 0.53$	PBS long version (Granié et al., 2013)	Granié et al. (2013)
Turkey		289	Not assessed	PBS (Nordfjærn et al., 2013)	Nordfjærn & Şimşekoğlu (2013)
Hungary	2018	526	$\alpha = 0.635$	PBS short version * (Granié et al., 2013)	Hógye-Nagy (2018)
United Kingdom	2019	695	$\alpha = 0.521$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
Greece	2020	249	$\alpha = 0.53$	PBS short version * (Granié et al., 2013)	Solmazer et al. (2020)
Turkey		145	$\alpha = 0.63$		
Kosovo		112	$\alpha = 0.76$		
Estonia		131	$\alpha = 0.68$		
Russia		176	$\alpha = 0.69$		
Eastern Mediterranean Region					
Pakistan	2016	161	Not assessed	PBS (Nordfjærn et al., 2013)	Nordfjærn & Zavareh (2016)
Iran		131	Not assessed		
	2021	520	$\alpha = 0.63$	PBS Long version (Granié & al., 2013)	Esmaili et al. (2021)
African Region					
Kenya	2019	544	$\alpha = 0.484$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Mcllroy, Plant et al. (2019)
Americas Region					
United States	2017	425	$\alpha = 0.58$	PBS Long version (Granié et al., 2013)	Deb, Strawdermann, DuBien et al. (2017)
Mexico	2020	730	$\alpha = 0.76$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Ruiz et al. (2020)
Southeast Asian Region					
Bangladesh	2019	532	$\alpha = 0.398$	PBQ	Mcllroy & al. (2019)
Thailand		317	$\alpha = 0.378$		

(Deb, Strawdermann, DuBien et al., 2017)					
Western Pacific Region					
China	2016	283	$\alpha = 0.78$	CPBS (Qu et al., 2016)	Qu et al. (2016)
	2018	625	$\alpha^1 = 0.72$ $\alpha^2 = 0.69$	CPBS (Qu et al., 2016)	Xu, Liu et al. (2018)
	2019	544	$\alpha = 0.544$	PBQ	Mclroy, Plant et al. (2019)
Vietnam		835	$\alpha = 0.495$	(Deb, Strawdermann, DuBien et al., 2017)	Dinh et a. (2020b)
	2020	835	$\alpha = 0.68$		
China	2021	543	$\alpha = 0.54$		Liu et al. (2021)

536 **Table 8: Validation table of the positive behaviours dimension by world regions (WHO).** The symbol  
537  $\alpha^1$  in the study by Xu, Liu et al. (2018) represents the driver sample and  $\alpha^2$  represents the non-driver sample.  
538 The symbol \* represents the versions modified by the authors before the questionnaire is released.

539

#### 540 **4 Discussion**

541 The main objective of this study was to gather all the knowledge in the literature on the PBS  
542 so that researchers have access to an overview of the different versions, their development,  
543 their uses and their limitations in terms of validation or study population. Our secondary  
544 objective was to analyze the validation of the dimensions of pedestrian behaviour around the  
545 world in order to propose possible improvements to this questionnaire. To do so, we reviewed  
546 publications that used the full PBS or one of its derivatives. We identified several shortcomings  
547 concerning the dimensional validation of pedestrian behaviour in the different versions of the  
548 questionnaire. A table summarising the items from the original long version that were used in  
549 the most replicated versions (PBS, CPBS, PPBQ) is available in the supplementary material  
550 (Table C).

551 First, concerning violation and errors, the validation results differentiate either the overall  
552 dimension of ‘transgressions’ or two independent dimensions, ‘violations’ and ‘errors’.  
553 Although the transgressions dimension was always found using the CPBS and the PBS of  
554 Nordfjærn et al. (2013), and was frequently found using the short or long version of the PBS,  
555 this dimension did not show sufficient internal consistency indicators with the use of the CBPS

556 (Xu, Liu et al., 2018a) and was only rarely found using Deb's PBQ (Dinh et al., 2020b). An  
557 overview of the different studies that have found the transgression dimension shows that  
558 these results do not seem to stem from the validation tests performed or the study population  
559 but rather from the version used. The CPBS was partly inspired by the PBS, and the  
560 transgression dimension found by PCA was interrogated by a total of six items, four of which  
561 were derived from the violations dimension ('I cross outside the pedestrian crossing even if  
562 there is one less than 50 m away', 'I cross the street even though the pedestrian light is red',  
563 'I cross even though the traffic light is still green for vehicles' and 'I cross while talking on my  
564 cell phone or listening to music on my headphones') and only one ('I cross between vehicles  
565 stopped on the roadway in traffic jams') from the errors dimension of the PBS (see Table C in  
566 the supplementary material). The last item ('I cross in between parked cars when there is a  
567 safer place to cross nearby') did not correspond to the PBS and should be taken from  
568 Nordfjærn et al. (2013). The eight items of the PBS seem to be more suitable for the evaluation  
569 of this dimension. However, as it has not been replicated in China, we cannot know whether  
570 the lack of internal consistency may be due to the selected items or to the study population,  
571 as the differentiation between violations and errors strongly depends on the road rules in  
572 place in the country. The transgression dimension was found in only one study using the PBQ  
573 (Dinh et al., 2020b). In contrast to McIlroy, Plant et al. (2019), Dinh et al. (2020b) validated the  
574 PBQ by PCA, not CFA, in a population from the Western Pacific region. This result allows us to  
575 note that the differentiation into two independent dimensions (violations and errors) does  
576 not seem to fit this population. Almost all studies that used the PBQ found both the violations  
577 dimension and the errors dimension. Comparing the two short versions of the PBS and the  
578 PBQ reveals differences in items. Although there is a change of only one item in the violations  
579 dimension ('Cross even though the light is still green for vehicles' in the PBS and 'I take



580 passageways forbidden to pedestrians to save time' in the PBQ), we see a radical change in  
581 the errors dimension. Only the item 'I cross between vehicles stopped on the roadway in  
582 traffic jams' is identical in both versions. In conclusion, the PBQ appears to be more  
583 appropriate than other versions for finding the violations and errors dimensions, but  
584 modifications can be made, as the internal consistency of these two dimensions appears to  
585 be insufficient for many countries (McIlroy, Plant et al., 2019; Ruiz et al., 2020; Liu et al., 2021).  
586 This version does not seem suited to the European, Southeast Asian and Western Pacific  
587 regions (McIlroy, Plant et al., 2019). Given that all other studies on populations in the  
588 European region and in the Western Pacific region found the transgressions dimension, the  
589 two independent dimensions of violations and errors do not seem to fit these populations.  
590 Thus, items in these dimensions could be explored in future studies.

591 Secondly, the dimension lapses was found in all versions of the questionnaire, but the CPBS  
592 was the only scale that did not show sufficient internal consistency (Qu et al., 2016; Xu, Liu et  
593 al., 2018). This dimension has only three items in the CPBS and the items used correspond  
594 either to the lapses dimension ('I cross without looking when I follow other people crossing'  
595 and 'I realise that I don't remember the path I have just taken') or to the error dimension ('I  
596 look at the traffic light and start crossing as soon as it turns red') of the long version of the PBS  
597 (see Table C in the supplementary material). Using the PBQ, McIlroy Plant, et al (2019) found  
598 sufficient internal consistency in the same population. Closer examination shows that none of  
599 these items are identical to the PBS and the shortened PBQ, both using four similar items: 'I  
600 realise that I have crossed several streets and intersections without paying attention to traffic',  
601 'I forget to look before crossing because I am thinking about something else', 'I cross without  
602 looking because I am talking with someone' and 'I forget to look before crossing because I  
603 want to join someone on the sidewalk on the other side'. The lack of internal consistency then

604 calls into question the relevance of adapting certain items to the population studied on this  
605 dimension. Thus, the lapses dimension of the CPBS should be revised using selected items  
606 from the PBS since it has already shown its effectiveness.

607 Third, the dimension of 'aggressive behaviour' was appropriately assessed using the short or  
608 long version of the PBS as well as O'Hern et al.'s (2020) questionnaire, which was not the case  
609 for Nordfjærn et al.'s version of the PBS, the CPBS and the PBQ. We note that the modified  
610 short version of Solmazer et al. (2020) achieved sufficient internal consistency with a three-  
611 item assessment. However, this dimension in Russia is composed of the three items of  
612 aggressive behaviour, but the PCA showed that one item from the dimension of lapses ('I  
613 realise that I have crossed several streets and intersections without paying attention to  
614 traffic') and one item from the dimension of positive behaviour ('I let a car go by, even if I have  
615 the right-of-way, if there is no other vehicle behind it') could also correspond to this factor. As  
616 positive behaviour is the opposite of aggressive behaviour, we can question the validity of this  
617 dimension. Nordfjærn and Zavareh's version of the PBS also had difficulty assessing this  
618 dimension (Nordfjærn & Zavareh, 2016) which is represented by only two items. Thus, the use  
619 of the original PBS might be more relevant for use in this region (Esmaili et al., 2021). The CPBS  
620 also experienced difficulty assessing aggressive pedestrian behaviour with sufficient internal  
621 consistency (Xu, Liu et al., 2018a). The lack of internal consistency could be due to the fact  
622 that one item in this dimension is not suitable for the assessment of aggressive behaviour.  
623 Indeed, the item 'I deliberately walk on the pavement when I could walk on the pavement or  
624 shoulder' included in this dimension would correspond to the violation dimension of the long  
625 version of the PBS (see Table C in the supplementary material). Thus, the PBQ showed  
626 sufficient internal consistency with respect to the Chinese population and the difference  
627 between these two versions is only with respect to this item. This item is replaced in the PBQ

628 by 'I have gotten angry with a driver and hit their vehicle' in the aggressive behaviour  
629 dimension, which has shown satisfactory internal consistency in many countries, including  
630 countries in the Western Pacific region (McIlroy, Plant et al., 2019; Ruiz et al., 2020; Dinh et  
631 al., 2020b; Liu et al., 2021). Based on this difference, we can assume that the item present in  
632 the CPBS is not part of the aggressive behaviour of pedestrians but of violations. Moreover,  
633 this item is the one that saturates the least on the PCA (0.60). We have noted that the PBQ  
634 worked well for assessing aggressive pedestrian behaviour in the Western Pacific region, the  
635 European region, and the Americas region, but this is not the case for the African region or  
636 the Southeast Asian region (McIlroy, Plant et al., 2019). In the Southeast Asian region, the PBQ  
637 successfully assessed aggressive behaviour in Thailand but not in Bangladesh. This could be  
638 explained by cross-cultural differences between the two study populations in terms of how  
639 aggressive behaviour is viewed. Several variables known to be related to pedestrian behaviour  
640 have been shown to differ between populations in this region, such as religion (Yildirim, 2007;  
641 McIlroy, Plant et al., 2019; McIlroy, Kokwaro et al., 2020) and transport modes (McIlroy & al.,  
642 2019). The composite version compiled by O'Hern et al. (2020) found this dimension  
643 independently of aggressive behaviour. The items used by O'Hern should be considered to  
644 assess this dimension in future studies.

645 Finally, the dimension of positive behaviours has rarely been assessed because of the lack of  
646 a sufficient internal consistency indicator. Using the PBS, Solmazer et al. (2020), who deleted  
647 the item 'I walk on the right side of the pavement so as not to obstruct pedestrians I meet'  
648 before releasing the questionnaire, found this dimension to be internally consistent in only  
649 one of the five European countries studied. This dimension showed internal consistency for a  
650 single PBQ replication (Ruiz et al., 2020). However, only one item differed between the PBS  
651 and PBQ: 'I stop to let pedestrians I meet pass' (PBS) and 'I thank a driver who stops to let me

652 cross' (PBQ). Although the CPBS version seems more appropriate to achieve sufficient internal  
653 consistency (Qu et al., 2016; Xu, Liu et al., 2018a), the PBS, CPBS and PBQ used 3 common  
654 items for the assessment of positive behaviour (see Table C in in the supplementary material).  
655 This difference does not seem to be explainable on the basis of culture as the use of the PBQ  
656 in China has not been shown to be adequate (McIlroy, Plant et al., 2019; Liu et al., 2021). The  
657 CPBS added an additional item, 'I stop to let pedestrians pass'. Although this item was the  
658 least saturated (0.64) in the PCA conducted by Qu et al. (2016), its addition in other versions  
659 of the PBS could perhaps provide sufficient internal consistency. Overall, this dimension  
660 proved difficult to assess using the different versions of the PBS. Indeed, the composite  
661 version compiled by O'Hern et al. (2020) did not find a dimension that could be equated with  
662 positive behaviours. Future studies must consider using new tools that have been created that  
663 can assess the role of positive behaviours in pedestrian behaviour. For example, by combining  
664 three previously validated questionnaires, the Driver Behaviour Questionnaire (DBQ; Reason  
665 & al., 1990), the Cycling Behaviour Questionnaire (CBQ; Useche & al., 2018) and the Bicycle  
666 Rider Behaviour Questionnaire (BRBQ; Hezaveh et al., 2018), Useche et al. (2020) validated a  
667 new scale called the Walking Behaviour Questionnaire, which includes the assessment of  
668 positive pedestrian behaviour with a sufficient indicator of internal consistency. Future  
669 research should consider the questionnaire created by Bazargan et al. (2020) which offers a  
670 broader view of positive pedestrian behaviours than current questionnaires. Indeed, the study  
671 by Bazargan et al. (2020) showed that positive behaviours explained a large part of the  
672 variance: 41.2% for positive behaviours (group 1) and 17.1% for positive behaviours (group 2).  
673 As the authors in that study did not rely on specific existing questionnaires, the positive  
674 behaviours dimension was shown to have a place in the analysis of pedestrian behaviour.

675 This study applied a rigorous systematic review methodology to analyze different aspects of a  
676 questionnaire used internationally to understand pedestrian behaviour. We rejected articles  
677 that only evaluated the internal consistency of the different dimensions using Cronbach's  
678 alpha coefficient, a practice that is currently highly debated. Indeed, factorial analysis remains  
679 an essential step in the interpretation of results, but the analysis of internal consistency using  
680 Cronbach's alpha coefficient is not sufficient to verify the validity of a scale (Hussey & Hughes,  
681 2020). Our current study brings together, for new researchers in the field of pedestrian  
682 behaviour, the totality of knowledge in the literature regarding the history, use, and  
683 modification of the PBS. It is thus able to assist researchers in deciding on a pedestrian  
684 behaviour assessment methodology appropriate to their hypotheses and population and  
685 provides new research perspectives. Since few studies using the PBS or one of its versions had  
686 the main objective of validating the questionnaire in the population studied, we selected all  
687 the studies that evaluated both the factor structure and the internal consistency of their  
688 questionnaire. We did not make a more precise selection concerning the factor analysis test  
689 used in their studies (PCA, EFA, CFA). Although we have taken this into account in the  
690 discussion to analyze the differences in terms of dimensions found and validated, this may  
691 present a bias in the overall view of validation of the different dimensions. Ideally, a  
692 comparison of the scales requires simultaneous tests of them under similar contexts. That  
693 would certainly require much more effort than a conceptual review. Currently, the internal  
694 consistency was the only indices we considered. However, in the future, systematic  
695 comparisons should be done in order to better understand the cultural effects on pedestrian  
696 behaviours. Thus, future questionnaire validation studies should consider the specific aspect  
697 of validation tests as they further advance research global research on pedestrian behaviour.

698 In addition, we selected studies that used at least 15 items from one of the PBS versions.  
699 However, the fact that some items were deleted before the questionnaire was disseminated  
700 may have influenced the lack of internal consistency and prohibited the evaluation of the  
701 dimension under consideration. To have a complete view, authors using one of the versions  
702 of the PBS should use the full version (long or short) of the questionnaire and present their  
703 validation results before and after the deletion of items.

704 Furthermore, to facilitate comparison of the different dimensions, we mapped each country  
705 to its world region. However, as the pedestrian behaviour studied by the PBS may differ from  
706 one country to another within the same world region (Solmazer et al., 2020; McIlroy, Plant et  
707 al., 2019), these results only represent a preliminary analysis. For example, the results for the  
708 African region only refer to results from Kenya, but it is difficult to say that these results would  
709 be similar in other countries on the African continent. The distribution of countries according  
710 to world region may be a bias in our study. Nine countries are associated with the European  
711 region, while only two countries are associated with the Southeast Asian region, and one  
712 country is associated with the African region. Thus, a country-specific comparison will enable  
713 a more objective view of the current situation of the PBS's evolution.

714 Finally, our finding may have been affected by factors other than the items used in different  
715 versions of the PBS. Some dysfunctions may have arisen as a consequence of the translation  
716 methodology used in the study. Indeed, few studies provided information regarding the  
717 translation of the questionnaire. Several steps are recommended for the translation of a  
718 questionnaire, such as back-translation (Brislin, 1970), which should be carried out by bilingual  
719 people familiar with both the terminology of the research field and the jargon of the target  
720 language (Sousa & Rojjanasrirat, 2010). A bilingual sample would be an optional but

721 interesting element to consider when assessing the clarity of items (Sousa & Rojjanasrirat,  
722 2010).

723 From this discussion it is apparent that the different versions of the pedestrian behaviour  
724 questionnaire are not always appropriate. These shortcomings can be explained by different  
725 factors that future studies must consider. By reviewing the validation of the questionnaires in  
726 a number of world regions, we have suggested advice for use and possible improvements to  
727 the different validated versions to best assess the different dimensions of pedestrian  
728 behaviour. The original PBS (Granié et al., 2013) or the version of Nordfjærn et al. (2013) seem  
729 to be more suitable for assessing the transgression dimension. The PBQ is a good alternative  
730 (Dinh et al., 2020b) but might be more suitable when the researcher wants to assess the two  
731 independent dimensions of violations and errors, due to the modifications made to the errors  
732 dimension. However, this tool is not usable in all world regions, and one study showed the  
733 potentiality of three independent dimensions (violations, errors and transgressions), which  
734 remains to be explored in future studies. The lapses dimension is usable with all  
735 questionnaires except the CPBS (Qu et al., 2016), which should be subject to modification  
736 using items from other versions. The short or long version of the PBS by Granié et al. (2013)  
737 seems to be the best option for assessing aggressive behaviour when not modified before the  
738 release of the study. Finally, the positive pedestrian behaviour dimension faces many  
739 validation difficulties. Although the CPBS version appeared to achieve sufficient internal  
740 consistency, the only difference between the PBQ and this questionnaire is the addition of a  
741 single item. As O'Hern et al. (2020) did not find a dimension that could be equated with  
742 positive behaviour after combining all versions, we propose that this dimension should be  
743 further investigated in future research with new pedestrian behaviour questionnaires to

744 determine whether this dimension is really part of pedestrian behaviour or whether this  
745 dimension would in fact be multidimensional.

## 746 **5 Conclusion**

747 As the aim of our systematic review was to assist researchers in assessing pedestrian  
748 behaviour, we summarized its history and its uses, and examined the validation of the  
749 different versions. No systematic review of this questionnaire has been conducted previously.  
750 Our paper will enable researchers to quickly make an informed choice of methodology for  
751 studying pedestrian behaviour and improve this questionnaire. To this end, we provide the  
752 following recommendations for use as well as possible improvements to the different  
753 validated versions in order to best assess the different dimensions of pedestrian behaviour: 1)  
754 assessment of the transgressions dimension using the PBS of Granié et al. (2013), Nordfjærn  
755 et al., (2013), or the PBQ of Deb, Strawdermann, DuBien et al. (2017) particularly when the  
756 researcher wishes to assess the two independent dimensions of violations and errors; 2)  
757 modification of the CPBS items (Qu et al., 2016) for the lapses dimension; 3) use of the short  
758 or long version of the PBS for the assessment of aggressive behaviours without modification  
759 prior to dissemination of the study; and 4) further research on the items of the positive  
760 dimension making use of newer pedestrian behaviour questionnaires and through a rigorous  
761 translation method. This study advises researchers of the most appropriate methodology to  
762 be able to fully assess the different dimensions of pedestrian behaviour and, consequently, to  
763 obtain results to answer the multiple research hypotheses related to pedestrian road safety  
764 to decrease pedestrian accidents in the world.

765

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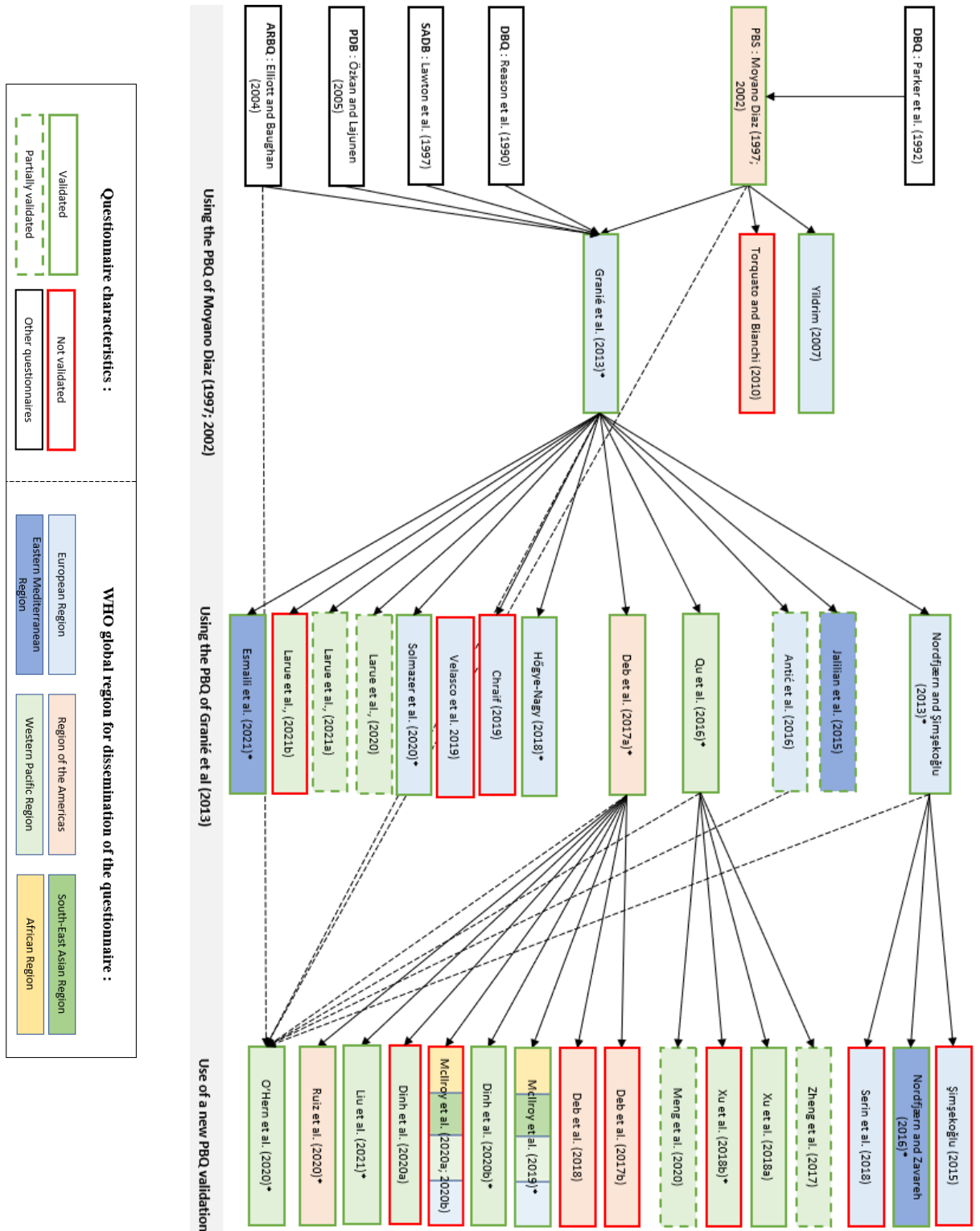
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1014 **Appendix:**

1015 **Figure A.: Summary graph of the use and validation of the PBS from 1997 to 2021.** Items circled in  
 1016 red represent PBSs validated by factor analysis and internal consistency checking. The colours  
 1017 represent the respective regions of the world according to the WHO classification of PBS use. The '\*'  
 1018 sign represents the questionnaires selected in our article on questionnaire validations.

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1024 **Supplementary material:**

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1026 **Table A.1.: Detailed table of individual variables associated with the different versions of the PBS.**

1027 This table includes studies using the PBS that have been fully or partially validated. This table does  
 1028 not include the basic socio-demographic measures used by most authors such as gender, age,  
 1029 education level, or marital status.

Measures		Authors	Link to pedestrian behaviour
<b>Socio-demographic measures</b>			
MacArthur scale of subjective socioeconomic status (Adler & al. 2000; Piff & al. 2010; Giatti & al. 2012)		Dinh et al., (2020a)	No
Marital status		Esmaili et al. (2021)	Yes
Having children			No
Income			Yes
<b>Variables concerning mobility</b>			
<b>As a road user</b>	Satisfaction level with the traffic infrastructure and environment	Nordfjærn & Şimşekoğlu (2013)	Yes
		Şimşekoğlu (2015)	Yes
	Daily hours in traffic	Nordfjærn & Şimşekoğlu (2013)	No
	Modes of transport	Hógye-Nagy (2018)	Yes
	Involvement in an accident as road user	Granié, Pannetier & Gueho (2013)	Yes
		McIlroy et al. (2019)	Yes
Ruiz, González-García & Bermúdez-Rivera (2020)		No	
<b>As a driver</b>	The possession of driving licence	Granié, Pannetier & Gueho (2013)	Yes
		Hógye-Nagy (2018)	Yes
		Esmaili, Aghabayk, Parishad & Stephens (2021)	Yes
	Owning a motor vehicle	Granié, Pannetier & Gueho (2013)	Yes
	Driving frequency		Yes
	Kilometers driven weekly		Yes
	Daily driving time	Hógye-Nagy (2018)	Yes
Esmaili, Aghabayk, Parishad & Stephens (2021)		Yes	

	Participation in traffic accidents as a driver	Esmaili, Aghabayk, Parishad & Stephens (2021)	Yes
<b>As a pedestrian</b>	Reasons for walking	Hőgye-Nagy (2018)	Yes
		Antić, Pešić, Milutinović & Maslač (2016)	Yes
	The daily distance that a pedestrian walked	Antić, Pešić, Milutinović & Maslač (2016)	Yes
	Walking frequency	Granié, Pannetier & Gueho (2013)	Yes
	Daily walking time	Granié, Pannetier & Gueho (2013)	No
	Walking time	Esmaili, Aghabayk, Parishad & Stephens (2021)	Yes
	Participation in traffic accidents as a pedestrian	Esmaili, Aghabayk, Parishad & Stephens (2021)	Yes
	Involvement in pedestrian-related motor vehicle collision as pedestrian	Deb, Strawderman, DuBien et al. (2017)	Yes
	Involvement in collision resulting in injury	Deb, Strawderman, DuBien et al. (2017)	Yes
	Severity of injury	Deb, Strawderman, DuBien et al. (2017)	Yes

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1031 **Table A.2: Detailed table of questionnaires associated with the different versions of the PBS.** This  
1032 table includes studies using the PBS that have been fully or partially validated.

Questionnaires	Authors	Link to pedestrian behaviour
<b>Questionnaires on attitudes in the road context</b>		
Attitudes toward other road users (Serin, Cansu, Bahar & Lajunen, 2018)	Serin et al. (2018)	Yes
Pedestrian attitudes scale (Iversen & Rundmo, 2004 ; Nordfjærn et Şimşekođlu, 2013)	Nordfjærn & Şimşekođlu (2013)	Yes
	Şimşekođlu (2015)	Yes
	Nordfjærn et Zavareh (2016)	Yes
Attitudes towards road safety (Iversen & Rundmo (2004) + Peltzer & Renner (2003))	McIlroy et al. (2020a ; 2020b)	Yes
	Dinh et al. (2020a; 2020b)	Yes
	Liu et al. (2021)	Yes
<b>Other road-related questionnaires</b>		
The Driver Behavior Questionnaire (DBQ; Reason et al. 1990)	Şimşekođlu (2015)	Yes
Pedestrian Inconvenience Questionnaire (PIQ) (Xu, Ge, Qu, Sun & Zhang, 2018)	Xu, Ge et al. (2018)	Yes
Traffic Climate Scale (TCS) (Zhang & al., 2018)	Xu, Ge et al. (2018)	Yes

Questionnaire of pedestrian receptivity toward FAVs (Deb, Strawderman, Carruth, DuBien, Smith, & Garrison, 2017)	Deb, Strawderman, Carruth et al. (2017)	Yes
	Deb et al., 2018	Yes

#### Risk perception questionnaires

Risk perception on the road (Nordfjærn and Rundmo, 2009)	Liu et al. (2021)	No
Traffic risk perception (Nordfjærn and Rundmo, 2009)	General traffic risks as using motorized vehicles	No
	Risks associated to vulnerable road users	No
	Traffic accident risks	Yes
Non-traffic risk perception (Fischhoff, Slovic, Lichtenstein, Read & Combs, 1978; Lund & Rundmo, 2009)	Food and health related risks	Yes
	Living style related risks	No
	Environment related risks	No
	Radiation related risks	No
	Risks caused by street crime and political unrest	No

#### Personality questionnaires

Measures of empathy (Loewen et al. 2010)	Şimşekoğlu (2015)	Yes
Measures of conformity (Mehrabian and Stefl 1995)	Şimşekoğlu (2015)	Yes
Personality scales (Goldberg (1999) ; Ulleberg & Rundmo (2003))	Qu et al. (2016)	Yes
Hexaco-Pi-R personality inventory (Ashton & Lee, 2010; Burtaverde, 2015)	Chraif (2019)	Yes
Personality scales (John & Srivastava, 1999)	Zheng et al (2017)	Yes

#### Questionnaires assessing psychological variables

Uncertainty avoidance (Jung & Kellaris, 2004)	Nordfjærn & Şimşekoğlu (2013)	No
Perceived Stress Scale-10 (Cohen et al., 1983)	Zheng et al (2017)	Yes
Primary School Student Self-Control Scale (Yang & Shen, 2013)	Meng, Ma, Shen & Chang (2020)	Yes
Theory of Planned Behaviour (Jalilian, Darani, Mahaki, Delpisheh & Rad, 2015)	Jalilian, Darani, Mahaki, Delpisheh & Rad (2015)	Yes

#### Questionnaires related to cognitive processes and consciousness

The Attention-Related Cognitive Errors Scale (ARCES) (Carciofo, Du, Song, & Zhang, 2014)	Qu et al. (2016)	Yes
	Xu, Liu et al. (2018)	Yes
The Mindful Attention Awareness Scale (MAAS) (Brown & Ryan, 2003; Deng & al., 2012)	Qu et al. (2016)	Yes
	Xu, Liu et al. (2018)	Yes

#### Questionnaires on cultural values and beliefs

	Nordfjærn & Şimşekoğlu (2013)	Yes
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The horizontal and vertical collectivism and individualism tool (Wasti & Erdil, 2007)	Nordfjærn et Zavareh (2016)	Not directly
Multidimensional fatalism scale / Fatalistic beliefs (Esparza & al., 2015)	McIlroy et al. 2020 - How	Yes
	Dinh et al 2020 - examining	Yes
	Liu et al. (2021)	Yes
Short-Schwartz's value scale (Lindeman and Verkasalo, 2005)	Solmazer et al. (2020)	Yes

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1034 **Table A.3. : Detailed table of experimental protocols associated with the different versions of PBS.**

1035 This table includes studies using the PBS that have been fully or partially validated.

Experimental protocols	Authors
Scenario-based questions	Deb, Strawderman, DuBien et al. (2017)
	Deb, Strawderman, Carruth et al. (2017)
Pedestrian simulator (Sween, Deb, Carruth, Waddell, & Furuichi (2016) ; Deb, , & al. (2017))	Deb, Strawderman & Carruth (2018)
Eye-tracking system	Larue, Watling, Black & Wood (2021)
	Larue & Watling (2021)
VR experiment (Payre,Cestac, and Delhomme, 2016)	Velasco et al. (2019)
Virtual environments	Deb, Strawderman & Carruth (2018)

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1038 **Table B: Summary table of factor analyses conducted by country and world region (WHO).** The

1039 anonymous 'PCA' stands for principal component analysis, 'EFA' for exploratory factor analysis and  
 1040 'CFA' for confirmatory factor analysis. This table highlights the different results for the first two  
 1041 dimensions of pedestrian behaviour: two independent dimensions (violations and errors) or one  
 1042 overall dimension (transgressions).

1043

Region	Country	Year	Number of participants	Transgressions	Violation & erreurs	Questionnaire used	Validati on test	Authors
European Region	France	2013	343	X		PBS long version (Granié et al., 2013)	PCA	Granié et al. (2013)
	United Kingdom	2019	695		X	PBQ (Deb, Strawdermann, DuBien et al., 2017)	CFA	McIlroy et al. (2019)
	Greece	2020	249	X		PBS short version* (Granié et al., 2013)	PCA	Solmazer et al. (2020)

	Turkey	2013	289	X		PBS (Nordfjærn et al., 2013)	PCA	Nordfjærn & Şimşekoğlu (2013)
	Turkey	2020	145	X		PBS short version* (Granié et al., 2013)	PCA	Solmazer et al. (2020)
	Hungary	2018	526	X		PBS short version* (Granié et al., 2013)	EFA	Hógye-Nagy (2018)
	Kosovo	2020	112	X		PBS short version* (Granié et al., 2013)	PCA	Solmazer et al. (2020)
	Estonia	2020	131	X				
	Russia	2020	176	X				
<b>Eastern Mediterranean Region</b>	Pakistan	2016	161	X		PBS (Nordfjærn et al., 2013)	PCA	Nordfjærn & Zavareh (2016)
	Iran	2016	131	X		PBS long version (Granié et al., 2013)	PCA	Esmaili et al. (2021)
	Iran	2021	520	X				
<b>African Region</b>	Kenya	2019	544		X	PBQ (Deb, Strawdermann, DuBien et al., 2017)	CFA	Mcllroy et al. (2019)
<b>Region of the Americas</b>	United States	2017	425		X	PBS long version (Granié et al., 2013)	CFA	Deb, Strawdermann, DuBien et al. (2017)
	Mexico	2020	730		X	PBQ (Deb, Strawdermann, DuBien et al., 2017)		Ruiz et al. (2020)
<b>Southeast Asia Region</b>	Bangladesh	2019	532		X	Strawdermann, DuBien et al., 2017)		Mcllroy et al. (2019)
	Thailand	2019	317		X			
<b>Western Pacific Region</b>	China	2016	283	X		CPBS (Qu et al., 2016)	PCA	Qu et al. (2016)
		2018	625	X			CFA	Xu et al., (2018)
		2019	544		X	PBQ (Deb, Strawdermann, DuBien et al., 2017)	CFA	Mcllroy et al. (2019)
		2021	543		X		PCA	Liu et al. (2021)
	Vietnam	2019	835		X		CFA	Mcllroy et al. (2019)
		2020	835	X			PCA	Dinh et al. (2020b)



Australia	2020	968	X (Deliberate violations)	32 items* (O'Hern et al., 2020)	EFA and PCA	O'Hern et al. (2020)
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1045 **Table C: Original long version of the PBS (Granié et al., 2013) and use of these items in later versions.**

1046 The colours indicate the reuse of the item in the Granié et al. (2013) version of the short PBS in blue,  
 1047 in the CPBS (Qu et al., 2016) in green and in the PBQ (Deb et al., 2017) in beige. The corresponding  
 1048 dimension in the authors' factor analysis is indicated. The "\*" sign at the end of an item means that  
 1049 the item has been included in all three versions. All 23 PBS items and all 20 PBQ items are presented.  
 1050 A total of 16 out of 18 CPBS items correspond to the items of the long version of the PBS. The remaining  
 1051 two CPBS items, inspired by Nordfjærn & Şimşekoğlu's (2013) questionnaire, do not correspond to the  
 1052 original PBS items: 'I cross in between parked cars when there is a safer place to cross nearby'  
 1053 corresponding to the transgression dimension and 'I stop to let the pedestrians I meet by'  
 1054 corresponding to the positive behaviour dimension.

Dimension	Items	Questionnaire		
		PBS Granié et al. (2013)	CPBS Qu et al. (2016)	PBQ Deb et al. (2017)
Violation	V1 I cross the street even though the pedestrian light is red.*	Violation	Transgression	Violation
	V2 I cross diagonally to save time.	Violation		Violation
	V3 I cross outside the pedestrian crossing even if there is one (crosswalk) less than 50 m away.*	Violation	Transgression	Violation
	V4 On a two-way street with no median, I cross the first part and wait in the middle of the roadway to cross the second part.			
	V5 I cross while talking on my cell phone or listening to music on my headphones		Transgression	
	V6 I cross even though the light is still green for vehicles.	Violation	Transgression	
	V7 I start walking across the street, but I have to run the rest of the way to avoid oncoming vehicles.			
	V8 I walk on the curb.			

	V9 I avoid using pedestrian bridges or underpasses for convenience, even if one is located nearby			
	V10 I take passageways forbidden to pedestrians to save time.			Violation
	V11 I deliberately walk on the roadway when I could walk on the sidewalk or on the shoulder.		Aggressive behaviour	
Errors	E1 I start to cross on a pedestrian crossing and I end up crossing it diagonally to save time.	Errors		
	E2 I cross between vehicles stopped on the roadway in traffic jams.*	Errors	Transgression	Errors
	E3 I cross the street between parked cars.	Errors		
	E4 I watch the traffic light and start crossing as soon as it turns red.		Lapses	
	E5 I walk on the roadway to be next to my friends on the sidewalk or to overtake someone who is walking slower than I am.	Errors		
	E6 I cross even though obstacles (parked vehicles, buildings, trees, trash bins, etc.) obstruct visibility.			
	E7 I cross even if vehicles are coming because I think they will stop for me.			Errors
	E8 I walk on cycling paths when I could walk on the sidewalk.			Errors
	E9 I run across the street without looking because I am in a hurry.			Errors
	E10 I walk on bicycle lanes when I could walk on the sidewalk.			
	E11 If a car is blocking the crosswalk, I will walk behind the car to cross the street.			
	E12 If a car is blocking the crosswalk, I will walk in front of the car when crossing the street.			
Lapses	L1 I cross without looking when following other people who are crossing.		Lapses	

	L2 I lose my way because I get lost in my thoughts.			
	L3 I realize that I do not remember the route I have just taken.		Lapses	
	L4 I have run into a pedestrian or an obstacle while walking because I am not paying attention.			
	L5 I realize that I have crossed several streets and intersections without paying attention to traffic.	Lapses		Lapses
	L6 I forget to look before crossing because I am thinking about something else.	Lapses		Lapses
	L7 I cross without looking because I am talking with someone.	Lapses		Lapses
	L8 I forget to look before crossing because I want to join someone on the sidewalk on the other side.	Lapses		Lapses
Aggressive behaviour	A1 I get angry with another road user (pedestrian, driver, cyclist, etc.), and I yell at him.	Aggressive behaviour		Aggressive behaviour
	A2 I walk in a way that forces other pedestrians to let me through.			
	A3 I cross very slowly to annoy a driver.		Aggressive behaviour	Aggressive behaviour
	A4 I get angry with another road user (pedestrian, driver, cyclist, etc.), and I make a hand gesture.*	Aggressive behaviour	Aggressive behaviour	Aggressive behaviour
	A5 I get angry with another road user (pedestrian, driver, cyclist, etc.), and insult him.	Aggressive behaviour	Aggressive behaviour	
	A6 I have gotten angry with a driver and hit their vehicle.	Aggressive behaviour		Aggressive behaviour
Positive behaviour	P1 I thank a driver who stops to let me cross.		Positive behaviour	Positive behaviour
(Reverse-scaled)	P2 I stop walking to let other pedestrians pass by.	Positive behaviour		
	P3 When I am accompanied by other pedestrians, I walk in single file on narrow	Positive behaviour	Positive behaviour	Positive behaviour

	sidewalks so as not to bother the pedestrians I meet.*			
	P4 I walk on the right-hand side of the sidewalk so as not to bother the pedestrians I meet.*	Positive behaviour	Positive behaviour	Positive behaviour
	P5 I let a car go by, even if I have the right-of-way, if there is no other vehicle behind it.*	Positive behaviour	Positive behaviour	Positive behaviour
	P6 On a two-way street with a median, I cross the first part and wait in the middle of the roadway to cross the second part.			
Filters	F1 I walk outdoors.			
	F2 I take public transportation (buses, metro, tramway, etc.).	Filters		
	F3 I walk without being accompanied.			
	F4 I walk for the pleasure of it.	Filters		
	F5 I walk in covered areas to avoid traffic (such as shopping centers).			
	F6 I walk accompanied by other people.			
	F7 I walk because I have no other choice.	Filters		

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