The pedestrian behaviour scale: A systematic review of its validation around the world

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Romane Vandroux[a], Marie-Axelle Granié[b], Mathilde Jay[a], Cédric Sueur[a,c], Marie Pelé[d]

[a] Université de Strasbourg, Institut Pluridisciplinaire Hubert Curien UMR 7178, CNRS de Strasbourg, France

Email adresses : romane.vandroux@iphc.cnrs.fr (Romane Vandroux), mathilde.jay@iphc.cnrs.fr (Mathilde Jay), cedric.sueur@iphc.cnrs.fr (Cédric Sueur)

[b] AME-MODIS, Univ Gustave Eiffel, IFSTTAR, Univ Lyon, F-69675 Lyon, France

Email adress : marie-axelle.granie@univ-eiffel.fr (Marie-Axelle Granié)

[c] Institut Universitaire de France, Paris, France

[d] Anthropo-Lab, ETHICS EA 7446, Lille Catholic University, France

Corresponding author: Marie Pelé, Lille Catholic University, marie.pele@univ-catholille.fr

Abstract

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

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

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

1.1.   Introduction

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

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

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

1.2. Literature review

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

Pedestrian Behaviour	Definition	Example	Reference
Violation	Deliberate deviation from social rules without intention to cause injury or damage.	Not using nearby pedestrian crosswalk to cross	Reason et al. (1990)
Error	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)
Lapse	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)
Aggressive Behaviour	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)

Positive Behaviour	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)

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

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

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

2   Method

2.1   Eligibility criteria and search strategy

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

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
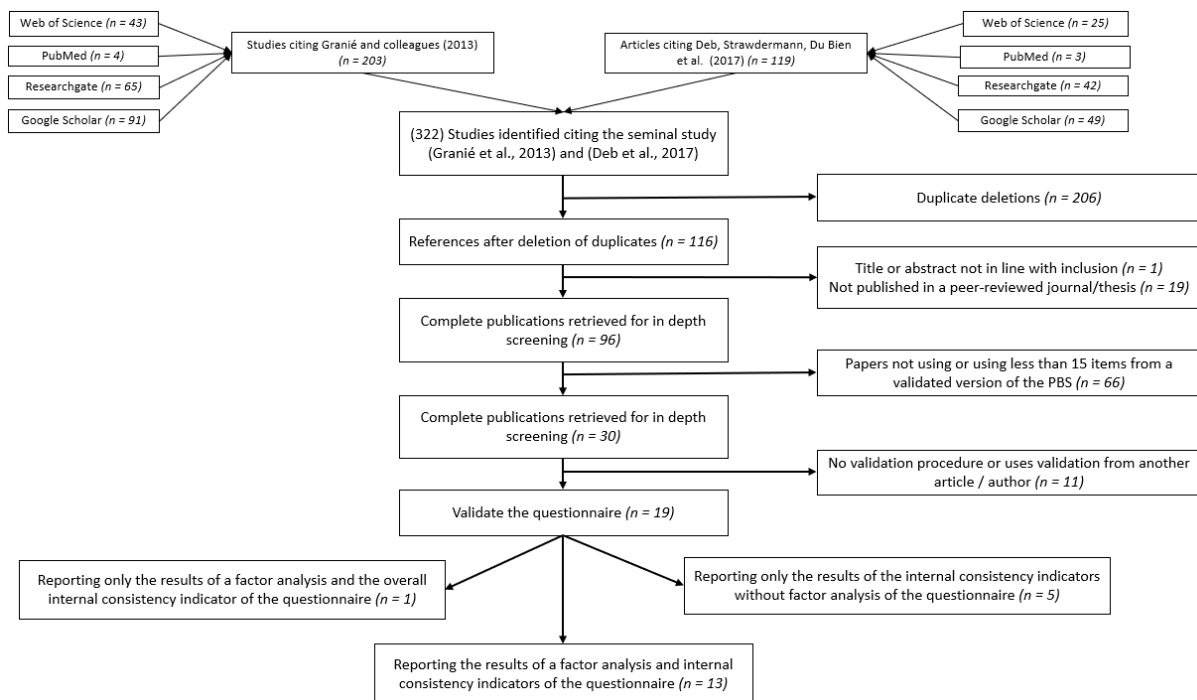
212 Figure 1. Flow chart for study collection

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.

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

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

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

Models	χ2	df	χ2 /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

Model 2: Transgressions (violations & errors), lapses, aggressive behaviors, and positive behaviors	1622.85	617	2.630	0.07	0.85	0.78
Model 3: 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
Model 4: Five factors (violations, errors, lapses, aggressive behaviors, and positive behaviors)	1528.79	613	2.494	0.06	0.89	0.82
Model 5: 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
Model 6: 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

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

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

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

fatalistic beliefs and general attitudes toward road safety in different countries. The extensive

data collected in this study has resulted in numerous studies that investigated the effect of

socio-demographic variables, fatalistic beliefs and attitudes toward road safety (Dinh et al.,

2020b; McIlroy, Kokwaro et al., 2020) as well as road risk perception (Dinh et al., 2020b;

McIlroy, Nam et al., 2020b) on pedestrian behaviour. Dinh et al. (2020a) reused data from the

Viet Nam-specific study by McIlroy, Plant et al. (2019) and investigated the role of fatalistic

beliefs about road safety attitudes on pedestrian behaviour. Very recently, Liu et al. (2021)

reused data pertaining to China from McIlroy, Plant et al. (2019) to examine the effects of

attitudes toward road safety, fatalistic beliefs, and risk perceptions on self-reported

pedestrian behaviour in a Chinese sample.

3.1.2   The first version of the PBS as a milestone

Since 2018, the original PBS has been used in a number of countries throughout the world

(Hungary, Romania, the Netherlands, Estonia, Greece, Kosovo, Russia, Turkey, New Zealand,

Iran). Hőgye-Nagy (2018) used the full 43-item PBS to present as the basis for the Hungarian

adaptation of the scale and to assess the most important characteristics of pedestrian traffic

in Hungary. Chraif (2019) used the shortened PBS in Romania to investigate whether

personality traits predicted positive pedestrian behaviour. It was used in the Netherlands

(Velasco et al., 2019) to examine the effect of the physical appearance of an automated vehicle

and an external human-machine interface (eHMI) on pedestrians' intention to cross, as well

as to assess the perceived realism of virtual reality based on 360° videos for pedestrian

crossing behaviour for research purposes. Solmazer et al. (2020) replicated the PBS in five

European countries: Estonia, Greece, Kosovo, Russia and Turkey. This study showed that there

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; McIllroy 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 (McIlroy, 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 (Hőgye-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 Hőgye-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	α = 0.89	PBS Long version (Granié et al., 2013)	Granié et al. (2013)
Turkey		289	α = 0.866	PBS (Nordfjærn et al., 2013)	Nordfjærn & Şimşekoğlu (2013)
Hungary	2018	526	α = 0.807	PBS short version * (Granié et al., 2013)	Hőgye-Nagy (2018)
Greece	2020	249	α = 0.82	PBS short version * (Granié et al., 2013)	Solmazer et al. (2020)
Turkey		145	α = 0.79		
Kosovo		112	α = 0.75		
Estonia		131	α = 0.78		
Russia		176	α = 0.85		
Eastern Mediterranean Region					
Pakistan	2016	161	α = 0.763	PBS (Nordfjærn et al., 2013)	Nordfjærn & Zavareh (2016)
Iran		131	α = 0.811		
	2021	520	α = 0.79	PBS Long version (Granié et al., 2013)	Esmaili et al. (2021)
Western Pacific Region					
China	2016	283	α = 0.72	CPBS (Qu et al., 2016)	Qu et al. (2016)
	2018	625	α^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)

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

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

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

The PBS was then adapted for an American population (Deb Strawdermann, DuBien et al., 2017). The PBQ showed satisfactory internal consistency in the African, American and Western Pacific regions (McIlroy, Plant et al., 2019; Liu et al., 2021) but not in the European and Southeast Asian regions (McIlroy, 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)	McIlroy, Plant et al. (2019)
African Region					
Kenya	2019	544	$\alpha = 0.715$	PBQ (Deb, Strawdermann, DuBien et al., 2017)	McIlroy, Plant et al. (2019)

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

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

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

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

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

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

3.3.2 Lapses

Details regarding the validation of the lapses dimension are presented in Table 6. This dimension is called 'attention violations' in the study by Nordfjærn and Şimşekoğlu (2013). It combines items from the lapses dimension (e.g. 'I realize that I have crossed several streets and intersections without paying attention to traffic') as well as the errors dimension (e.g. 'I cross even if vehicles are coming because I think they will stop for me') of the PBS. This dimension also contains items added from their own observations referring to situations on the road with the use of technology (e.g. 'When I cross the road using a cell phone, I forget to look properly') or when the individual has been drinking alcohol (e.g. 'When I have been drinking alcohol, I am less likely to use pedestrian crossings'). In their factor analysis, O'Hern et al. (2020) found a dimension similar to lapses, which the authors called 'unintentional errors'. Using Granié et al.'s (2013) long, short, or modified versions of the PBS, Nordfjærn and Şimşekoğlu's (2013) PBS version, as well as the PBQ, the items seem to match satisfactorily with the totality of the studied world regions. However, there was a lack of internal consistency regarding this dimension in China (Qu et al., 2016; Xu, Liu et al., 2018), especially 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	α = 0.83	PBS Long version (Granié et al., 2013)	Granié et al. (2013)
Turkey		289	α = 0.857	PBS (Nordfjærn et al., 2013)	Nordfjærn & Şimşekoğlu (2013)
Hungary	2018	526	α = 0.771	PBS short version * (Granié et al., 2013)	Hőgye-Nagy (2018)
United Kingdom	2019	695	α = 0.867	PBQ (Deb, Strawdermann, DuBien et al., 2017)	McIlroy, Plant et al. (2019)
Greece	2020	249	α = 0.91	PBS short version * (Granié et al., 2013)	Solmazer et al. (2020)
Turkey		145	α = 0.90		
Kosovo		112	α = 0.86		
Estonia		131	α = 0.83		
Russia		176	α = 0.93		
Eastern Mediterranean Region					
Pakistan	2016	161	α = 0. 746	PBS (Nordfjærn rt al., 2013)	Nordfjærn & Zavareh (2016)
Iran		131	α = 0.747		
	2021	520	α = 0.81	PBS Long version (Granié et al., 2013)	Esmaili et al. (2021)
African Region					
Kenya	2019	544	α = 0.835	PBQ (Deb, Strawdermann, DuBien et al., 2017)	McIlroy & al. (2019)
Region of the Americas					
United States	2017	425	α = 0.90	PBS Long version (Granié et al., 2013)	Deb, Strawdermann, DuBien et al. (2017)
Mexico		730	α = 0.77	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Ruiz et al. (2020)
Southeast Asian Region					
Bangladesh	2019	532	α = 0.843	PBQ (Deb, Strawdermann, DuBien et al., 2017)	McIlroy, Plant et al. (2019)
Thailand		317	α = 0.842		
Western Pacific Region					
China	2016	283	α = 0.61	CPBS (Qu et al., 2016)	Qu et al. (2016)
	2018	625	$α^1$ = 0.38 $α^2$ = 0.40	CPBS (Qu & al., 2016)	Xu, Liu et al. (2018)
	2019	544	α = 0.863	PBQ (Deb, Strawdermann, DuBien et al., 2017)	McIlroy, Plant et al. (2019)
Vietnam		835	α = 0.838		
	2020	835	α = 0.87		Dinh et al. (2020b)
Australia	2020	968	α = 0.87	32 items* (O'Hern et al., 2020)	O'Hern & al. (2020)
China	2021	543	α = 0.86	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Liu et al. (2021)

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

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	α = 0.70	PBS long version (Granié et al., 2013)	Granié et al, (2013)
Turkey		289	α = 0.837	PBS (Nordfjærn et al., 2013)	Nordfjærn & Şimşekoğlu (2013)

Hungary	2018	526	α = 0.636	PBS short version * (Granié et al., 2013)	Hőgye-Nagy (2018)
United Kingdom	2019	695	α = 0.766	PBQ (Deb, Strawdermann, DuBien et al., 2017)	McIlroy, Plant et al. (2019)
Greece	2020	249	α = 0.86	PBS short version * (Granié et al., 2013)	Solmazer et al. (2020)
Turkey		145	α = 0.86		
Kosovo		112	α = 0.90		
Estonia		131	α = 0.78		
Russia		176	α = 0.91 (+1 Lapses et 1PB)		
Eastern Mediterranean Region					
Pakistan	2016	161	α = 0.657	PBS (Nordfjærn et al., 2013)	Nordfjærn et Zavareh (2016)
Iran		131	α = 0.674		
	2021	520	α = 0.75	PBS long version (Granié e al., 2013)	Esmaili et al. (2021)
African Region					
Kenya	2019	544	α = 0.675	PBQ (Deb, Strawdermann, DuBien et al., 2017)	McIlroy, Plant et al. (2019)
Region of the Americas					
United States	2017	425	α = 0.88	PBS long version (Granié et al., 2013)	Deb, Strawdermann, DuBien et al. (2017)
Mexico	2020	730	α = 0.73	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Ruiz et al. (2020)
Southeast Asian Region					
Bangladesh	2019	532	α = 0.687	PBQ (Deb, Strawdermann, DuBien et al., 2017)	McIlroy, Plant et al. (2019)
Thailand		317	α = 0.778		
Western Pacific Region					
China	2016	283	α = 0.64	CPBS (Qu et al., 2016)	Qu et al. (2016)
	2018	625	α^1 = 0.71 / α^2 = 0.68	CPBS (Qu et al., 2016)	Xu, Liu et al. (2018)
	2019	544	α = 0.887	PBQ (Deb, Strawdermann, DuBien et al., 2017)	McIlroy, Plant et al. (2019)
Vietnam		835	α = 0.858		
	2020	835	α = 0.86		Dinh et al. (2020b)
Australia	2020	968	α = 0.86	32 items* (O'Hern et al., 2020)	O'Hern et al. (2020)
China	2021	543	α = 0.89	PBQ (Deb, Strawdermann, DuBien et al., 2017)	Liu et al. (2021)

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

3.3.4 Positive behaviours

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

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

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

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

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

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

4 Discussion

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

First, concerning violation and errors, the validation results differentiate either the overall dimension of 'transgressions' or two independent dimensions, 'violations' and 'errors'. Although the transgressions dimension was always found using the CPBS and the PBS of Nordfjærn et al. (2013), and was frequently found using the short or long version of the PBS, 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

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

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

by 'I have gotten angry with a driver and hit their vehicle' in the aggressive behaviour

dimension, which has shown satisfactory internal consistency in many countries, including

countries in the Western Pacific region (McIlroy, Plant et al., 2019; Ruiz et al., 2020; Dinh et

al., 2020b; Liu et al., 2021). Based on this difference, we can assume that the item present in

the CPBS is not part of the aggressive behaviour of pedestrians but of violations. Moreover,

this item is the one that saturates the least on the PCA (0.60). We have noted that the PBQ

worked well for assessing aggressive pedestrian behaviour in the Western Pacific region, the

European region, and the Americas region, but this is not the case for the African region or

the Southeast Asian region (McIlroy, Plant et al., 2019). In the Southeast Asian region, the PBQ

successfully assessed aggressive behaviour in Thailand but not in Bangladesh. This could be

explained by cross-cultural differences between the two study populations in terms of how

aggressive behaviour is viewed. Several variables known to be related to pedestrian behaviour

have been shown to differ between populations in this region, such as religion (Yildirim, 2007;

McIlroy, Plant et al., 2019; McIlroy, Kokwaro et al., 2020) and transport modes (McIlroy & al.,

2019). The composite version compiled by O'Hern et al. (2020) found this dimension

independently of aggressive behaviour. The items used by O'Hern should be considered to

assess this dimension in future studies.

Finally, the dimension of positive behaviours has rarely been assessed because of the lack of

a sufficient internal consistency indicator. Using the PBS, Solmazer et al. (2020), who deleted

the item 'I walk on the right side of the pavement so as not to obstruct pedestrians I meet'

before releasing the questionnaire, found this dimension to be internally consistent in only

one of the five European countries studied. This dimension showed internal consistency for a

single PBQ replication (Ruiz et al., 2020). However, only one item differed between the PBS

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.

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Appendix:

Figure A.: Summary graph of the use and validation of the PBS from 1997 to 2021. Items circled in

red represent PBSs validated by factor analysis and internal consistency checking. The colours

represent the respective regions of the world according to the WHO classification of PBS use. The '*'

sign represents the questionnaires selected in our article on questionnaire validations.
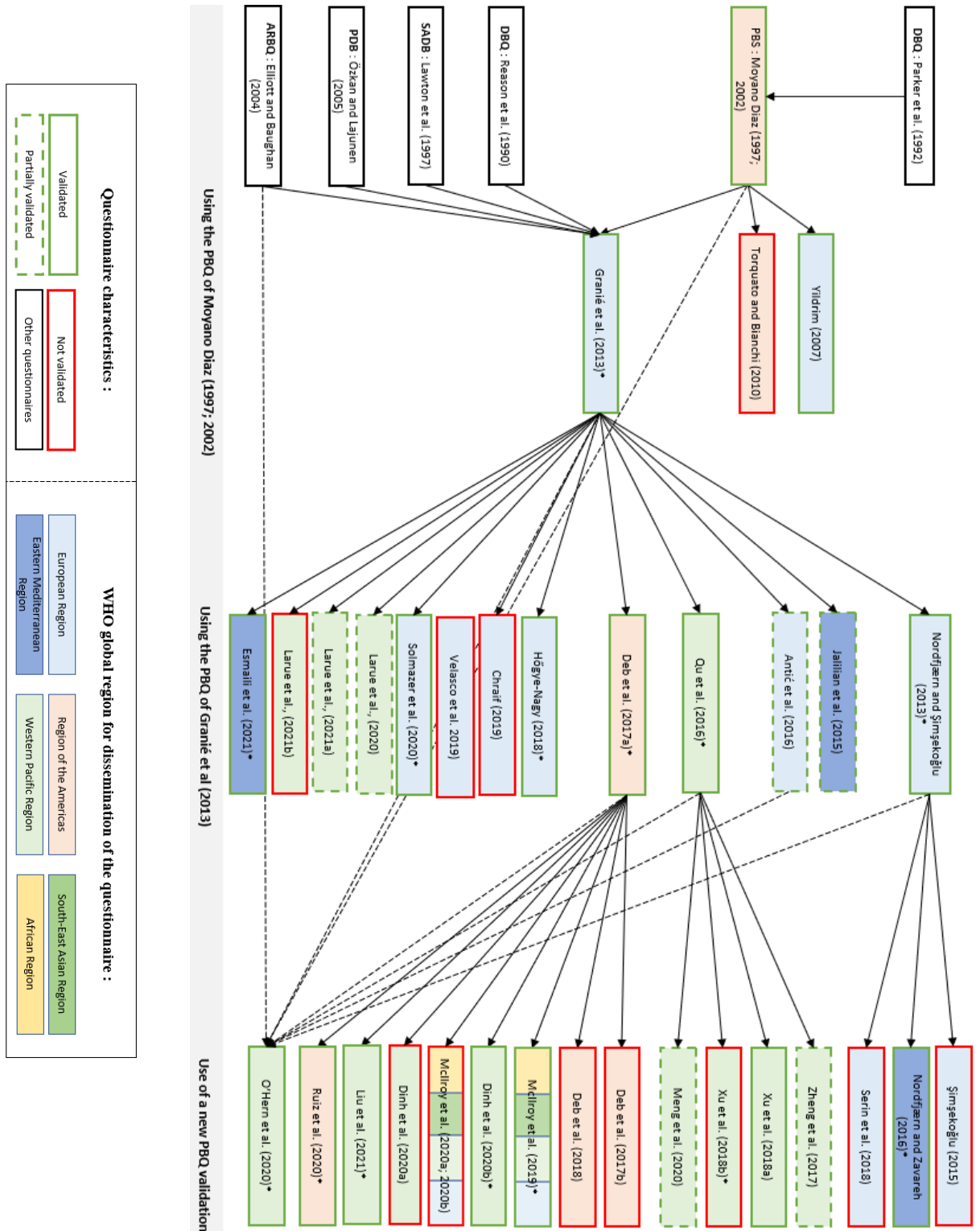
1024 **Supplementary material:**

1025

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
Socio-demographic measures			
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
Variables concerning mobility			
As a road user	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	Hőgye-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
As a driver	The possession of driving licence	Granié, Pannetier & Gueho (2013)	Yes
		Hőgye-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	Hőgye-Nagy (2018)	Yes
		Esmaili, Aghabayk, Parishad & Stephens (2021)	Yes

	Participation in traffic accidents as a driver	Esmaili, Aghabayk, Parishad & Stephens (2021)	Yes
As a pedestrian	Reasons for walking	Hőgye-Nagy (2018)	Yes
		Antić, Pešić, Milutinović & Maslać (2016)	Yes
	The daily distance that a pedestrian walked	Antić, Pešić, Milutinović & Maslać (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
Questionnaires on attitudes in the road context		
Attitudes toward other road users (Serin, Cansu, Bahar & Lajunen, 2018)	Serin et al. (2018)	Yes
Pedestrian attitudes scale (Iversen & Rundmo, 2004 ; Nordfjærn et Şimşekoğlu, 2013)	Nordfjærn & Şimşekoğlu (2013)	Yes
	Şimşekoğlu (2015)	Yes
	Nordfjærn et Zavareh (2016)	Yes
Attitudes towards road safety (Iversen & Rundmo (2004) + Peltzer & Renner (2003))	McIllroy et al. (2020a ; 2020b)	Yes
	Dinh et al. (2020a; 2020b)	Yes
	Liu et al. (2021)	Yes
Other road-related questionnaires		
The Driver Behavior Questionnaire (DBQ; Reason et al. 1990)	Şimşekoğlu (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	Dinh et al. (2020b)	No
	Risks associated to vulnerable road users		No
	Traffic accident risks		Yes
Non-traffic risk perception (Fischoff, Slovic, Lichtenstein, Read & Combs, 1978; Lund & Rundmo, 2009)	Food and health related risks	Dinh et al. (2020b)	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

Experimental protocols	Authors
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)	McIllroy 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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Table A.3. : Detailed table of experimental protocols associated with the different versions of PBS.

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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Table B: Summary table of factor analyses conducted by country and world region (WHO). The anonymous 'PCA' stands for principal component analysis, 'EFA' for exploratory factor analysis and 'CFA' for confirmatory factor analysis. This table highlights the different results for the first two dimensions of pedestrian behaviour: two independent dimensions (violations and errors) or one overall dimension (transgressions).

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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)

Region	Country	Year	N			Instrument	Analysis	Reference
	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	Hőgye-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				
Eastern Mediterranean Region	Pakistan	2016	161	X		PBS (Nordfjærn et al., 2013)	PCA	Nordfjærn & Zavareh (2016)
	Iran	2016	131	X				
	Iran	2021	520	X		PBS long version (Granié et al., 2013)	PCA	Esmaili et al. (2021)
African Region	Kenya	2019	544		X	PBQ (Deb, Strawdermann, DuBien et al., 2017)	CFA	McIlroy et al. (2019)
Region of the Americas	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)
Southeast Asia Region	Bangladesh	2019	532		X			McIlroy et al. (2019)
	Thailand	2019	317		X			
Western Pacific Region	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	McIlroy et al. (2019)
		2021	543		X		PCA	Liu et al. (2021)
	Vietnam	2019	835		X		CFA	McIlroy 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)

Table C: Original long version of the PBS (Granié et al., 2013) and use of these items in later versions.

The colours indicate the reuse of the item in the Granié et al. (2013) version of the short PBS in blue, in the CPBS (Qu et al., 2016) in green and in the PBQ (Deb et al., 2017) in beige. The corresponding dimension in the authors' factor analysis is indicated. The "*" sign at the end of an item means that the item has been included in all three versions. All 23 PBS items and all 20 PBQ items are presented. A total of 16 out of 18 CPBS items correspond to the items of the long version of the PBS. The remaining two CPBS items, inspired by Nordfjærn & Şimşekoğlu's (2013) questionnaire, do not correspond to the original PBS items: 'I cross in between parked cars when there is a safer place to cross nearby' corresponding to the transgression dimension and 'I stop to let the pedestrians I meet by' 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 (Reverse-scaled)	P1 I thank a driver who stops to let me cross.		Positive behaviour	Positive behaviour
	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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