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The impact of a child bike seat and trailer on the objective overtaking behaviour of motorized vehicles passing cyclists

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ABSTRACT

Introduction: The lateral clearance distance of a motorized vehicle while overtaking a cyclist is a key indicator of safety. This lateral clearance distance has never been measured for cyclists transporting a child. Therefore the aim of this study was to investigate the behaviour of motorized vehicles in overtaking cyclists with and without a child on the same bicycle.

Methods: The lateral clearance distance of the overtaking manoeuvres of motorized vehicles was measured using an instrumented bicycle when performing 19 cycling trips on one single road with two different types of cycling infrastructure (a bike lane and shared lane marking) in the Brussels Capital Region (Belgium). Mixed effect regression was used to examine the effect of cycling condition (cyclist without a child [control], cyclist with a child bike seat and cyclist with a child bike trailer) and secondary independent variables (i.e. cycling infrastructure, peak traffic hours and traffic density) on the lateral clearance distance.

Results: The mean lateral clearance distance in 'cyclists without child' was significantly smaller (117.3 cm) than in 'cyclists with child' (128.8 cm) (95%CI [7.2;15.9]). Looking at 'morning peak traffic hours' (i.e. 7:00 to 9:00 a.m.) a cyclist with child bike seat was overtaken at greater lateral clearance distances than a cyclist with a child bike trailer or a cyclist without child (p=0.041). Furthermore, the percentage of passing manoeuvres under 100 cm was significantly higher in 'cyclist without child' (35.3%) in comparison to 'cyclist with child bike seat' (21.8%) and 'cyclist with child bike trailer' (21.8%) (Chi2=29.19, p<0.001). No significant differences were found between a shared lane marking and bike lane.

Conclusion: Drivers of motorized vehicles do adapt their overtaking manoeuvre when they overtake cyclists transporting a child, keeping greater and therefore safer lateral clearance distances. In morning peak traffic hours and/or crowded circumstances the child bike seat can be considered as the safest way to transport a child in terms of lateral clearance distance. In general, with 25.3% overtaking manoeuvres under 100cm, police should monitor compliance with the traffic rules with regard to cyclists, and motorists should be more aware of the overtaking traffic rules.

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1. Introduction

Cycling for transport contributes to many fitness and health-related benefits. Cycling in general and more specific commuting are effective and feasible ways to meet the public health recommendations for physical activity (e.g. minimal 30 minutes of moderate-to-vigorous intensity a day) (WHO, 2010). The health-enhancing benefits related to cycling are extensive. Indisputable evidence for primary and secondary prevention of non-communicable diseases (i.e. cardiovascular diseases, cancers, chronic respiratory diseases and diabetes) is found in different studies (Celis-Morales et al., 2017; De Hartog, Boogaard, Nijland, & Hoek, 2010). Regular physical activity not only affects physical health, but also mental health experiences benefits, such as a reduction of anxiety, stress and depression (Avila-Palencia et al., 2017; Martin, Goryakin, & Suhrcke, 2014; Warburton, Nicol, & Bredin, 2006). Commuting also offers some environmental benefits, such as reduced greenhouse gases, noise reduction and improved air quality (Woodcock et al., 2009).

Regrettably cycling (for transport) does not always provide positive effects at the level of the individual. In particular, there is always some risk of injury (e.g. single bicycle crash or vehicle-bicycle collision) with potentially serious consequences (Feleke, Scholes, Wardlaw, & Mindell, 2018; Mueller et al., 2015). In Belgium the number of cyclists involved in a crash in 2019 was 10 384 (2.3% higher than 2018), of which 91 were fatalities (8.3% higher than 2019) (VIAS, 2019). For the Brussels Capital Region (BCR) the number of victims was 192, which is 52,4% higher than in 2018 (VIAS, 2019). A large number (77%) of those bicycle crashes occurs from bicycle-vehicle collisions, rather than single bicycle crashes (VIAS, 2018a).

One specific form of bicycle-vehicle interaction that warrants further investigation, is the overtaking behaviour of motorized vehicles relative to cyclists. Although collisions during overtaking are less common than collisions at intersections, the speeds involved are usually higher during overtaking manoeuvres (Stone & Broughton, 2003), often leading to injuries that are more severe than those at intersections (McCarthy & Gilbert, 1996; Pai, 2011; Stone & Broughton, 2003; Haworth et al., 2014). Additionally, we need to be concerned with closer overtaking even when no actual collision takes place. Close passes are much more common than actual collisions and are more strongly associated with perceived danger than actual collisions (Sanders, 2015). The perceived danger often discourages people from cycling more frequently or from cycling at all (Mueller et al., 2015), thus reducing the many population health benefits that cycling offers.

Therefore, reducing close passing offers valuable benefits both for the direct risks of cycling and for the perceptions of cycling safety more generally. According to research by Dozza, Schindler, Bianchi-Piccinini, and Karlsson (2016) the minimum lateral clearance of a vehicle while overtaking a cyclist is a key indicator of safety. In Belgium a minimum lateral clearance distance of 100 cm in the built-up area and 150 cm outside the built-up area has been included in the traffic Law. Different standards apply in different countries, so each country has to be looked at separately. For example, in France the same standards as in Belgium are applied, in the Netherlands and the UK there are no standards and in other countries, like Spain, 150 cm is used as standard. Factors that might affect the lateral clearance distance of the motorized vehicle can be subdivided in three categories: (i) factors related to the motorized vehicle, (ii) factors related to the road infrastructure and (iii) factors related to the cyclist themselves.

In several studies the impact of vehicle type on the overtaking behaviour was examined. Although the division of vehicle types was different in the undermentioned studies, substantial differences were observed. In general HGV's were found to pass closer than other vehicle categories (Walker, 2007). It is likely this is a behavioural response to physical constraints: large professional vehicles tend to be long and wide, and so must cross to the other side of the road for longer during an overtaking manoeuvre (Chapman & Noyce, 2014; Dozza et al., 2016; Kay, Savolainen, Gates, & Datta, 2014; Llorca, Angel-Domenech, Agustin-Gomez, & Garcia, 2017). This might also explain the finding of Kay et al. (2014), who found greater lateral clearance distances in motorcycles compared to passenger vehicles. Other studies also found a significant correlation between oncoming traffic and the overtaking distance, concluding that distances were smaller if oncoming vehicles were alongside the overtaking vehicle (Chapman & Noyce, 2014; Dozza et al., 2016; Kay et al., 2014; Llorca et al., 2017).

In a related way, physical constraints linked to the road environment also influence overtaking manoeuvres, which are sometimes transient (i.e. oncoming traffic) (Chapman & Noyce, 2014; Dozza et al., 2016; Kay et al., 2014; Llorca et al., 2017). However, fixed factors in the built environment that influence driver behaviour are more common. The direction of the road (i.e. tangent vs. curved) was found to have a notable influence on the lateral overtaking distance, with higher lateral clearance observed on tangent road sections (Llorca et al., 2017), and wider roads are associated with more generous passing than narrow roads (Mchale & Stewart, 2014; Shackel & Parkin, 2014). Similarly, the presence of cycle lanes and centrelines can have substantial influences (Chapman & Noyce, 2012; Mchale & Stewart, 2014; Shackel & Parkin, 2014). Shackel and Parkin (2014) suggested the removal of the centreline to be a very cost-effective way of increasing the level of comfort for cyclists. Similar results were found by Kay et al. (2014), where closer overtaking distances were observed when a centreline was present. But not all built-environment signals to motorists are equal: research on road signs promoting safe passing showed no significant effects on lateral clearance (Kay et al., 2014).

The final element in the lateral clearance distance of the motorized vehicle relative to cyclist, is the cyclist themselves. Significant greater lateral clearance distances were measured for cyclists riding closer to the edge of the road or the cycling lane (Chapman & Noyce, 2014; Kay et al., 2014; Olivier & Walter, 2013; Walker, 2007). In addition, Chapman and Noyce

(2014) showed by varying the cycling speed, that the speed of the cyclist had a significant positive influence, meaning a greater lateral clearance distance in slower cyclists.

Finally, some studies have suggested the appearance of the overtaken cyclist can influence motorists' behaviour. Systematic changes in average passing proximities have been observed as a function of such variables as rider gender, with greater overtaking distances in women (Operational & Impacts, 2011; Walker, 2007). Other aspects of appearance such as helmet use and visual cues were investigated by Walker and colleagues (Walker, 2007; Walker, Garrard, & Jowitt, 2014; Walker & Robinson, 2019). Smaller lateral distances were measured in cyclist wearing a helmet (2007; 2019) and greater lateral clearance distances were measured for cyclists wearing a 'police/video recording' outfit (2014).

Given this evidence on how lateral distance varies according to vehicle, roadway and rider characteristics, it appears that motorists' behaviour during a given overtaking manoeuvre is an instantaneous response to a range of factors, not merely a standard action. In other words, drivers do not merely execute the same overtake each time they pass a cyclist: they might 'tune' their behaviour to the perceived needs of the specific cyclist in front of them, taking into account physical constraints from the vehicle and the roadway.

What has not yet been investigated is the effect of transporting a child on the overtaking behaviour of motorists. According to our hypothesis, the perception of the driver of the motorized vehicle will be influenced by the presence of a child on the bicycle, which will possibly cause an adapted overtaking manoeuvre of the motorized vehicle.

Therefore the aim of this cross-sectional study is to investigate how motorized vehicles overtake a cyclist without (control) and with a child (carried on a child seat or a child bike trailer), by objectifying the 'overtaking behaviour' with lateral clearance measurements between the motorized vehicle and the bicycle.

2. Methods

2.1. Study area

The Brussels Capital Region is a condensed urban area of 161 km^2 (STIB, 2017), with a dense, very congested network of urban motorways, multi-lane avenues and boulevards. The cycling infrastructure consists of a network of physically separated bicycle lanes, dedicated bicycle lanes, bus and cycle lanes, bicycle marking lanes and other recommended cycling routes with road surface signage. The average annual growth in the number of cyclists is 13% counted for the period 2010-2018 (Velo, 2018). However, the BCR is not known as a bike friendly city, as is shown in the recent 2019 Global City Index, where Brussels is ranked 55th out of the 90 rated cities based on crime and safety, infrastructure, bike sharing and events (Ag, 2019).

2.2. Study design

2.2.1. Procedure

Two of the researchers (i.e. Ampe T. and Durlet H.) collected data on the overtaking behaviour of motorized vehicles in overtaking cyclists by performing 19 cycling trips conducted over different days and hours, in the Brussels Capital Region (BCR). Approximately the same number of cycling trips were performed by each of the researchers. Due to practical and time related reasons this sampling was not randomized (Table 1). Therefore, as the observations were acquired by cluster sam-

Table 1
Overview of data sampling

Day	Session*	Cycling condition	Cyclist	N obs
Friday 08-03-2019	14.11 - 16.57h	Without child	Ampe T.	225
Tuesday 12-03-2019	08.13 – 08.38h	Without child	Durlet H.	40
	11.05 – 11.12h	With child bike trailer	Durlet H.	8
Tuesday 19-03-2019	09.02 – 09.49h	Without child	Ampe T.	70
Thursday 21-03-2019	08.25 – 09.26h	Without child	Durlet H.	66
	11.11 – 11.34h	Without child	Ampe t.	36
	13.29 – 14.22h	With child bike trailer	Durlet H.	59
	15.43 – 16.34h	With child bike trailer	Ampe T.	95
Friday 22-03-2019	08.41 – 09.56h	With child bike trailer	Durlet H.	85
	15.13 – 17.10h	With child bike trailer	Durlet H.	194
Tuesday 26-03-2019	08.35 – 09.16h	With child bike seat	Ampe T.	95
	11.12 – 11.54h	With child bike seat	Durlet H.	46
	14.42 – 15.41h	With child bike seat	Durlet H.	87
Thursday 28-03-2019	09.03 – 10.02h	With child bike seat	Durlet H.	74
	11.12 – 12.11h	Without child	Ampe T.	19
	11.32 – 11.59h	With child bike seat	Ampe T.	21
	12.01 – 12.11h	With child bike trailer	Ampe T.	31
	15.40 – 16.38h	With child bike seat	Ampe T.	136
	17.35 – 18.06h	With child bike trailer	Durlet H.	30

* session is interpreted as an uninterrupted period of cycling up and down the street by one cyclist in one cycling condition. N. obs = 1423

pling (19 bike sessions spanning 7 days and divided among 2 cyclists), the 1 423 observations are not completely independent which must be taken into account. Within-cluster correlations (even after accounting for the independent variables) may occur because of differences in local and nearby traffic conditions, weather, instrument calibration and variability in the behavior of the cyclist. Mixed effects models were used in the analysis to account for this, and to quantify the extent to which these variables were associated with systematic patterns in passing proximities.

Only overtaking manoeuvres of motorized vehicles (i.e. cars, vans, trucks and buses) in the same direction of cycling were included in the present study, overtaking manoeuvres of all other vehicle types (i.e. cyclists, mopeds, monowheels, Segways, hoverboards, etc.), priority vehicles (i.e. police, ambulance, etc.) and head-on traffic were excluded.

In order to exclude as many external factors as possible, the following aspects were standardised:

- Both researchers had a similar anthropometric appearance and were consistently dressed like a regular commuter cyclist (i.e. sneakers, long pants, winter coat and blue/white cycling helmet)
- The cyclist was riding at the centre of either the non-separated bike lane or the shared traffic lane
- The cyclist was travelling at a speed between 13 and 17 kilometres per hour
- Good visibility, with daylight, no rain and no fog
- The rider remained in the saddle during the whole trip

2.2.1.1. Cyclist. Three different cycling conditions were included in this study. The first condition was a regular commuter cyclist without a child on the bicycle. The other two cycling conditions included the same commuter cyclist using the same bicycle, but with a child. The child was transported in a child bike seat (Fig. 1) or a child bike trailer (Fig. 2) respectively. To create the illusion of transporting a child, a doll was used, consisting of a stuffed ski suit with a plastic ball serving as head (Fig. 1). From the perspective of the motorized vehicle, coming from behind the bicycle, no clear distinction could be made between the doll and a real child.

2.2.1.2. Cycling infrastructure. In this study one specific flat bidirectional road without a centreline, located in the BCR, was used for all the cycling trips. The selected road consisted of two types of cycling infrastructure. Along one side of the road there was a shared lane marking and on the other side of the road there was a bike lane, as shown in figure 3. The shared lane marking is legally seen as a part of the road, so a minimal lateral clearance distance of 100 cm is mandatory. Besides, the bike lane is treated as an on-street separated cycle lane, so it is forbidden to drive on the bike lane with a motorized vehicle, but there is no minimum lateral clearance distance to overtake.

2.2.1.3. Traffic. Information on 'peak traffic hours' and traffic density was collected. In Belgium and the BCR, peak traffic hours are defined as the 'morning peak traffic hours' from 7:00 to 9:00 a.m. and the 'evening peak traffic hours' from 3:00 to 6:00 p.m. (VIAS, 2018b). Because the theoretical peak traffic hours do not always correspond to the actual traffic density, the actual traffic density was calculated as the number of overtaking manoeuvres for each timeframe of 10 minutes. The calculated traffic density was then used to dichotomise the overtaking manoeuvres into 'not-crowded' and 'crowded' using the median as cut-off point (i.e. 3.43 overtaking manoeuvres per cycling infrastructure type per 10 minutes).

2.2.2. Equipment

For the present study a regular touring bicycle (i.e. Oxford Highland Tracking X-perience) was used (Fig. 1 & 2). The bicycle was equipped with a transversely mounted MaxBotix MB1200 XL-MaxSonar-EZ0 temperature-compensated ultrasonic

Fig. 1. Child bike seat

Fig. 2. Child bike trailer

Fig. 3. The different cycling infrastructure types on the road used for the cycling trips

distance sensor (accuracy of ±1cm), based upon the sensor design used in Walker, Garrard, and Jowitt (2014). This sensor (sampling frequency 10 Hz) fed directly into an Arduino Uno prototyping computer running customised software. The sensor measured the lateral distance with a frequency of 10 times per second. The sensor, Arduino and batteries were housed in a small grey plastic box mounted on the bicycle's luggage rack, with its centre 78 cm from road level, facing perpendicularly to the direction of travel. The sensor and software were calibrated in a controlled environment.

The CSV-files on the SD card were afterwards processed using specially written software in MATLAB. Since the sensor was not mounted on the outermost point of the bicycle, a constant of 23cm was subtracted from the measured clearance distance for 'cyclist without child' and 'cyclist with child bike seat' and 45 cm for 'cyclist with child bike trailer'.

2.3. Data analysis

All statistical analyses were conducted in R 3.6.1 (R Development Core Team, R., 2011) using the lme4 (Bates, Mächler, Bolker, & Walker, 2015), AICcmodavg (Mazerolle, 2017) and lmerTest (Kuznetsova, Brockhoff, & Christensen, 2017) packages. For each category of overtaking manoeuvres (i.e. according to cycling condition, cycling infrastructure type and peak traffic hours) descriptive statistics (i.e. number of observations (N), means, standard deviations (SD), minimums, quartiles and maximums) were calculated. Thereafter, the lateral clearance distance of each overtaking manoeuvre was analysed both as a continuous measure and also dichotomised into a 'unsafe' overtaking manoeuvre (i.e. < 100 cm) and a 'safe' overtaking manoeuvre (i.e. > 100 cm). The percentage of 'unsafe' overtaking manoeuvres was then calculated for each cycling condition. Differences in percentage of 'illegal' overtaking manoeuvres between the cycling conditions was analysed using a Chi2 test.

To examine the effect of cycling condition (i.e. without child, with child bike seat and with child bike trailer) and secondary independent variables (i.e. cycling infrastructure, peak traffic hours and traffic density) on the continuous variable lateral clearance distance, linear mixed-effects regression was used. As a first step, different random effects structures were compared. Random effects were included to account for the correlation in the data due to cluster-sampling. The best random effects structure was then kept stable in the next step to compare the models with different fixed effect structures. A multi-model inference strategy was used to select a mixed effects regression model which best approximated the underlying data-generating model (Burnham & Anderson, 2004). To answer the primary research question (i.e. the effect of cycling condition on the lateral clearance distance) each model included dummy variables to model their effect with respect to the normal cycling condition. Besides the baseline model containing only cycling condition, thirteen additional models were fitted, containing additive and/or interaction effects with the other independent variables (i.e. cycling infrastructure, peak traffic hours and traffic density). The corrected Akaike Information Criterion (AICc) was used to guide model selection amongst the set of potential models. Based on the AICc, the relative weight or probability of each model (AICcWt) were computed, and the cumulative weight for the best set of models was obtained to find a 95% confidence set and evidence ratios (ratio of weights). For the models in the 95% confidence set, Type III ANOVA's (Satterthwaite approximations) were applied to test the significance of the main and interaction effects. Model averaging will be performed for all parameters that turn up in different models in the 95% confidence set to get more accurate estimates (Burnham & Anderson, 2004).

3. Results

A total of 1 423 overtaking manoeuvres was recorded. None of these overtaking manoeuvres was excluded for not meeting the inclusion criteria (i.e. overtaking manoeuvres of motorized vehicles in the same direction of cycling). When comparing the mean lateral clearance distance of the overtaking manoeuvres for both test persons, no significant difference was found (mean difference=1.6 cm, 95%CI [-2.6;5.9]).

The overall mean lateral clearance distance measured in the present study was 125 cm (95%CI [123; 127]). The mean lateral clearance distance recorded for cyclists without a child was 117 cm and 130 and 128 cm for cyclists with a child bike seat and child bike trailer respectively, which were significantly greater than without a child (mean diff.= 13 and 12 cm). After this, each of the overtaking manoeuvres was subdivided in a specific category according to the cycling condition (i.e. 'cyclist without child', 'cyclist with child bike seat' or 'cyclist with child bike trailer'), the cycling infrastructure type (i.e. 'shared lane marking' or 'bike lane') and the peak traffic hours (i.e. 'off peak', 'morning peak' or 'evening peak'). The number of overtaking manoeuvres in each category can be found in Table 2, as well as the means and the quantiles of the lateral clearance distance in each category. With the exception of three categories, the mean lateral clearance distance in all categories was significantly greater than 100 cm.

Nevertheless, at the same time, 25.3% of all the overtaking manoeuvres was under 100 cm. Since different rules apply on the two types of cycling infrastructure (i.e. shared lane marking and bike lane), the percentage of overtaking manoeuvres under the 100 cm was calculated for both types of infrastructure. With 24.4 and 26.2% of the overtaking manoeuvres under 100cm on the shared lane marking and the bike lane respectively, no significant difference was found between the two types of cycling infrastructure (Chi^2=0.61, p=0.436). A significant difference in the percentage of overtaking manoeuvres under the 100 cm was found between 'cyclist without child', 'cyclist with child bike seat' or 'cyclist with child bike trailer'. The percentage of passing manoeuvres under 100 cm was significantly higher in 'cyclist without child' (35.3%) in comparison to 'cyclist with child bike seat' (21.8%) and 'cyclist with child bike trailer' (21.8%) (Chi2=29.19, p<0.001).

Table 2
Descriptive statistics of corrected lateral clearance distance (cm) and percentage of illegal overtaking manoeuvres (<100cm)

Cycling condition	Cycling infrastructure	Peak traffic hours	Mean	±SD	Min.	Q1	Median	Q3	Max.	N obs
Total	/	/	125*	41	8	99	124	145	351	1423
Cyclist without child	/	/	117*	38	46	91	115	137	318	456
Cyclist with child bike seat	/	/	130*	45	21	106	127	147	351	463
Cyclist with child bike trailer	/	/	128*	38	8	105	126	148	337	504
Cyclist without child	Bike lane	Off peak	127*	36	46	102	127	154	233	100
		Morning peak	97	45	50	71	87	108	304	45
		Evening peak	121*	38	60	97	119	137	290	93
	Shared lane marking	Off peak	120*	35	49	95	121	140	318	119
		Morning peak	97	31	47	71	97	121	159	35
		Evening peak	117*	35	59	95	117	133	282	64
Cyclist with child bike seat	Bike lane	Off peak	129*	32	48	111	131	144	217	100
		Morning peak	123*	46	45	93	124	139	303	38
		Evening peak	139*	57	40	109	127	157	327	84
	Shared lane marking	Off peak	130*	37	42	107	130	153	230	97
		Morning peak	124*	33	67	100	123	137	222	28
		Evening peak	129*	54	21	97	123	146	351	116
Cyclist with child bike trailer	Bike lane	Off peak	139*	37	82	113	137	156	337	83
		Morning peak	107	25	65	91	105	123	157	13
		Evening peak	125*	39	27	102	122	142	333	122
	Shared lane marking	Off peak	134*	37	40	108	134	154	243	81
		Morning peak	129*	40	61	107	123	138	213	13
		Evening peak	123*	36	8	102	124	144	214	192

* significant ($p \leq 0.05$) different of the 100cm norm; N: Number; SD: Standard Deviation; Min.: Minimal; Max.: Maximal

3.1. Random effects structure

Table 3 reports the multimodel inference for choosing the optimal random effects structure. The fixed effects structure was kept fixed for this comparison and included only the primary independent variable (i.e. cycling condition). This table shows that the random effects structure could be modelled best using only random intercepts for session. Although sessions are nested within cyclist which are crossed with days, these more complex random effect structures yielded no better fit or resulted in singular models or had convergence issues (likely due to small number of days in a short period of time and the inclusion of only two cyclists). Also, the addition of random slopes for the fixed effect of cycling condition resulted in a singular model. The likelihood ratio test comparing the optimal random effects model to a naïve model without random effects was significant, indicating the importance of their presence in the model (Chi^2 =14.18; $p<0.001$)

3.2. Mixed effects regression

Using the random effects structure obtained in the first step, models with increasing complexity of the fixed effects structure were compared. Table 4 shows an overview of the best-fitting models until the cumulative weight is 100%. Eight other models were fitted but resulted in negligible weight contribution. Amongst the set of candidate models, the best fit was obtained for the model with main effects for cycling condition and peak traffic hours and their interaction. This model contained approximately half of the probability (AIC_cWt=0.52) amongst all models and was respectively 2.17 and 2.60 times better than the second and third best models. The top three models constituted a 95% confidence set, i.e. 95% certainty level that amongst the set of models examined, one of these three is closest to the true underlying model.

All three models in this set contain main effects of cycling condition and peak traffic hours, indicating that these effects are likely to be part of the underlying data generating mechanism. The main effect of infrastructure and the interaction effect between cycling condition and peak traffic hours were only present in one of the tree models.

Table 5 gives an overview of the coefficients of models 1-3. As the residuals showed considerable deviations from normality and transformations of the dependent variable were not able to remedy this, the 95%CI for the parameters were recalculated with bootstrapping (B=5000) to avoid bias. This yielded very similar results to the likelihood-based calculations for every model indicating robustness of the results. Type III ANOVA tests associated with each factor showed some significant effects. The two recurring factors in the 95% confidence set (i.e. main effects of cycling condition and peak traffic hours) were significant in each model ($p<0.005$), with respectively greater lateral clearance distances in both child conditions (i.e. cyclist with child bike seat and cyclist with child bike trailer) compared to the cyclist without a child and smaller later clearance distances in the morning peak compared to off-peak traffic hours. The main effect of infrastructure in model 2 was not sta-

Table 3
Overview of random effects model.

	Model formula (in lme4 syntax)	K	AICc	ΔAICc	AICcWt	AICcWt CumWt	ev. Ratio	Dec. Var.
1	Y ~ CC + (1|Se)	2	14538.48	0.00	0.54	0.54	1.00	2.8%
2	Y ~ CC + (1|Cy) + (1|Se:Cy)	3	14540.27	1.79	0.22	0.76	2.54	2.8%
3	Y ~ CC + (1|Day) + (1|Se:Day)	3	14540.50	2.02	0.20	0.96	2.70	3.2%
4	Y ~ CC + (1|Day) + (1|Se:Day) + (1|Cy) + (1|Se:Cy)	5	14544.31	5.83	0.03	0.99	18.00	3.2%
5	Y ~ CC + PTHd + I + RE	4	14546.81	8.33	0.01	1.00	54.00	10.7%

Each model included the same fixed effect (CC = cycling condition).
All models are fitted with restricted maximum likelihood.
Y= corrected lateral clearance distance; K= number of variance parameters; Se= indicator variable of session; Cy= indicator variable of cyclist; Day= indicator variable of day. Models 3, 4 and 5 resulted in singular fit.
Dec. Var.= declarative variance of the random effects model on the lateral clearance distance

Table 4
Overview of top models with different fixed effects

	Model formula (in lme4 syntax)	K	AICc	ΔAICc	AICcWt	AICcWt CumWt	ev. Ratio
1	Y ~ CC * PTH + RE	11	14536.01	0.00	0.52	0.52	1.00
2	Y ~ CC + PTH + I + RE	8	14537.57	1.56	0.24	0.75	2.17
3	Y ~ CC + PTH + RE	7	14537.94	1.92	0.20	0.95	2.60
4	Y ~ CC * PTHd + RE	8	14543.11	7.10	0.01	0.97	52.00
5	Y ~ CC + PTHd + I + RE	7	14543.16	7.14	0.01	0.98	52.00
6	Y ~ CC + PTHd + RE	6	14543.31	7.30	0.01	1.00	54.00

All models included the same random effects (RE = (1|session))
K= number of fixed effect parameters; Y= corrected lateral clearance distance; CC= cycling condition (without child, child bike seat, child bike trailer); PTH= peak traffic hours (off peak, morning peak, evening peak); PTHd= peak traffic hours dichotomized (off peak, peak hours); I= infrastructure (bike lane, shared lane); ΔAICc= difference in AICc between best model and other models; AICWt= probability (weight) that among the set of candidate models, this model is closest to the true underlying model; AICc CumWt= cumulative weights; ev.ratio: evidence ratio = ratio of weights between best model and other models.

Table 5
Overview of parameter estimates, standard errors and 95% CI of model 1-3 and the model average

$Y_{ij} = \beta_0 + b_{0j} + \beta_{1x1ij} + \beta_{2\ x2ij} + \beta_{3x3ij} + \beta_{4\ x4ij} + \beta_{5\ x1ij\ x3ij} + \beta_{6\ x2ij\ x3ij} + \beta_{7\ x1ij\ x4ij} + \beta_{8\ x2ij\ x4ij} + \beta_{9x5ij} + \varepsilon_{ij} b_{0j} \sim N(0; \upsilon^2)$: random intercepts for sessions$\varepsilon_{ij} \sim N(0; \sigma^2)$: residual variancej = 1 … 19, i = 1 … n_j (number of observations per session)

		Model 1		Model 2		Model 3		Model average	
		estimate	**95% CI**	**estimate**	**95% CI**	**estimate**	**95% CI**	**estimate**	**95% CI**
Intercept	**β0**	123.35	[117.72; 129.39]	123.21	[116.91 ; 129.33]	121.51	[115.52 ; 127.28]	122.94	[117.06 ; 128.82]
CC	**β1**	6.54	[-1.89; 14.85]	12.82	[5.33 ; 20.24]	12.77	[5.25 ; 20.34]	9.40	[-0.39 ; 19.18]
	β2	13.02	[3.95; 21.64]	11.43	[4.14 ; 19.47]	11.36	[4.04 ; 19.47]	12.28	[4.17 ; 20.38]
PTH	**β3**	-26.14	[-37.29; -15.54]	-17.30	[-24.92 ; -9.44]	-17.05	[-24.68 ; -9.18]	-22.05	[-34.85 ; -9.25]
	β4	-4.03	[-12.84 ; 4.72]	-4.671	[-10.28 ; 0.99]	-4.65	[-10.26 ; 1.06]	-4.32	[-11.7 ; 3.07]
CC x PTH	**β5**	20.03	[4.29 ; 36.97]	/	/	/	/	20.03	[4.3 ; 35.75]
	β6	9.02	[-11.21 ; 30.33]	/	/	/	/	6.90	[-5.15 ; 18.96]
	β7	6.90	[-6.02 ; 19.06]	/	/	/	/	9.02	[-10.69 ; 28.73]
	β8	-8.14	[-20.07 ; 4.90]	/	/	/	/	-8.14	[-20.03 ; 3.75]
I	**β9**	/	/	-3.30	[-7.48 ; 0.89]	/	/	-3.30	[-7.48 ; 0.88]
	σ	39.63	[38.21 ; 41.15]	39.66	[38.24 ; 41.17]	39.69	[38.27 ; 41.20]	/	/
	υ	1.97	[0.00 ; 6.00]	3.70	[0.00 ; 7.06]	3.75	[1.20 ; 7.10]	/	/

x_1= 1 for observation with child seat (0 otherwise)
x_2= 1 for observation with child trailer (0 otherwise)
x_3= 1 for observation in morning peak traffic hours (0 otherwise)
x_4= 1 for observation in evening peak traffic hours (0 otherwise)
x_5= 1 for observation on the bike lane (0 otherwise)
Reported are the likelihood-based 95% CI, very similar values were obtained based on 5000 random bootstrap simulations;
CC= cycling condition (without child, child bike seat, child bike trailer); PTH= peak traffic hours (off peak, morning peak, evening peak); I= infrastructure (bike lane, shared lane)

tistically significant (F=2.392; p=0.122); only a very small difference between the two cycling lanes was found (± 3cm). The interaction between cycling condition and peak traffic hours (model 1) was only right below the a-priori threshold of 0.05 (F=2.894, p=0.041); further evidence will be necessary to confirm the presence of this interaction effect.

The coefficients obtained by model averaging are summarized in Table 5. The model average allows us to perceive more accurate estimates of the fixed effects included in the 3 models of the 95% confidence set. The model average shows a positive significant effect of cycling with a child bike trailer on the lateral clearance distance, with greater lateral distances (+12.28 cm) compared to cycling without a child. The effect of a child bike seat was smaller (+9.4 cm) and not significantly different compared to without child. For the peak traffic hours it was found that cycling in the morning peak caused overtaking manoeuvres with smaller lateral clearance distances (-22.05 cm), which was significantly smaller than in the off-peak traffic hours. The lateral clearance distances in evening peak did not differ significantly from off-peak hours. Considering the interaction effect between cycling condition and peak traffic hours, it was observed that the overall decrease in lateral clearance distance during the morning peak was diminished in the condition with a child bike seat (-22.05 + 22.03 = -2.02 cm),

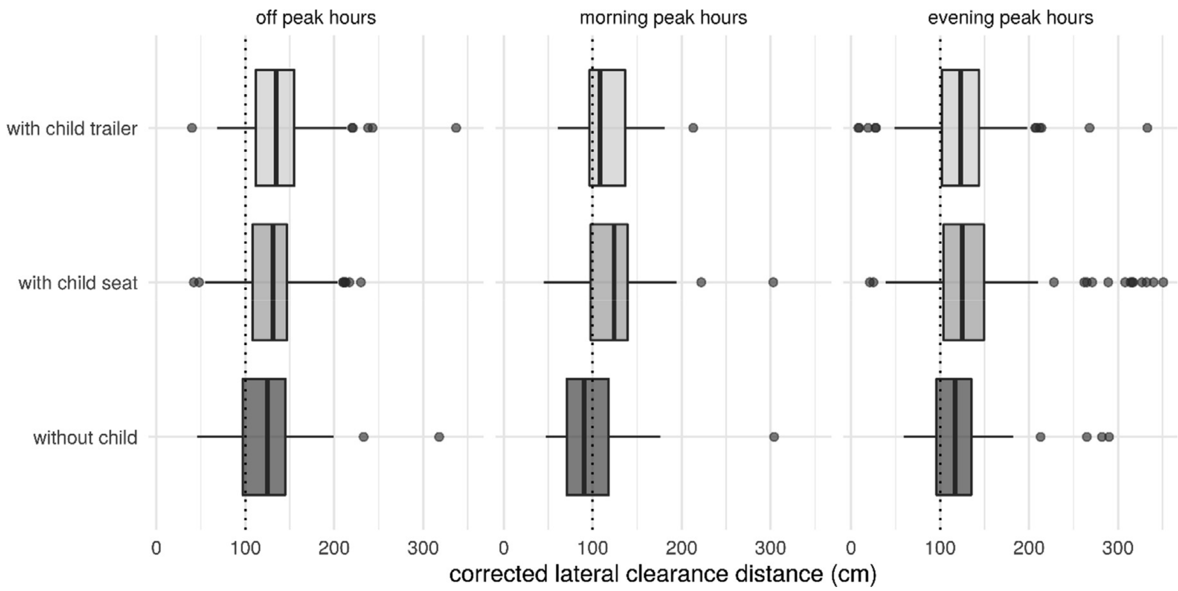

Fig. 4. Corrected lateral clearance distance (cm) for each cycling condition based on peak traffic hours

but not in the condition with child bike trailer (-22.05 + 6.90 = -15.15 cm) (Fig. 4). For the changes in the evening peak, no significant differences between cycling condition were observed.

4. Discussion

The present study extends earlier studies examining the behaviour of motorized vehicles in overtaking cyclists, in order to make cycling, and commuting in particular, a safer and a more attractive means of transport. This is the first documented study examining the effects of transporting a child on a bicycle on the overtaking behaviour of motorized vehicles. Conforming our working hypothesis that the perception of motorists is influenced by the appearance of a child carried on a bicycle, significant differences were observed between overtaking manoeuvres for different cycling conditions (i.e. 'cyclist without child', 'cyclist with child', 'cyclist with child bike seat' and/or 'cyclist with child bike trailer').

Most fundamentally, when comparing the lateral clearance distance in 'cyclist without child' with the lateral clearance distance in 'cyclist with child', we found a greater lateral clearance distance in 'cyclist with child'. Drivers of motorized vehicles executed their overtaking manoeuvre with a greater lateral clearance distance when they notice that the cyclist is transporting a child on the same bicycle. This finding is in line with earlier conclusions in Walker et al. (2014), who studied the effects of altering the way the cyclist was dressed. The authors suggest in their conclusion that drivers of motorized vehicles adjust their overtaking behaviour based on relatively subtle changes in the situation. Therefore, future studies may also investigate whether the presence of a child is necessary in order to increase the lateral clearance, or if the presence of a child bike seat and trailer without a child or other equipment (e.g. large bike bags) results in the same effects.

For parents of young children, traffic safety is an important factor in choosing their means of transport when transporting their children. When these parents carry a child on their bicycle, safety might even play a more important role. According to Dozza et al. (2016) the minimum lateral clearance of a vehicle while overtaking a cyclist is definitely a key indicator of safety. The main aim of this study was to identify the safest way of transporting a child by bicycle, in terms of lateral clearance distance during an overtaking manoeuvre. To this end, two different means of transporting children by bike (i.e. child bike seat and child bike trailer) were compared to each other and to a control group (i.e. cyclist without child).

Besides cycling condition, peak traffic hours was contained in all models of the 95% confidence set, indicating that these are likely part of the underlying data generating mechanism (Burnham & Anderson, 2004). Looking at the estimates of the model average, it is found that both transporting modes for children caused a greater lateral clearance distance of the overtaking motorized vehicle, but only the child bike trailer yields significantly greater lateral distances. According to this finding we may conclude, that independent of peak traffic hours, cycling infrastructure type and traffic density, drivers of motorized vehicles overtake cyclists with a child seated in a child bike trailer in a safer way, in terms of lateral clearance distance, as compared to a cyclist without child and with a child bike seat. When looking in more detail at the estimates of the model average, it is found that both peak traffic hours had a smaller lateral clearance distance. These results confirm that, independent of cycling condition, cycling infrastructure type and traffic density, drivers of motorized vehicles overtake cyclists in off-peak hours and evening peak hours in a safer way compared to the morning peak hours.

The second nuance is that Model 1 included the interaction effect of cycling condition and peak traffic hours. When both peak traffic hours and cycling condition were taken into account, different results were found. Looking at 'morning peak traffic hours', the period of the day where overall the lowest passing distances were measured, a cyclist with child bike seat was overtaken at greater lateral clearance distances than a cyclist with a child bike trailer or a cyclist without child. This finding implies that during morning peak traffic hours it is safer to transport a child in a child bike seat in terms of lateral clearance distance. This assumption gains further momentum when looking at 'crowded' traffic density levels. Here, once again, greater lateral clearance distances were found for 'cyclists with child bike seat' when compared with the control condition. This difference is absent when 'cyclist with child bike trailer' is compared with the control condition. If other similar studies can confirm these results, policy makers may consider to promote the child bike seat when developing new policies on transporting a child on the same bicycle.

The differences in lateral clearance distance between the child bike seat and the child bike trailer conditions are interesting as they indicate the extent to which motorists do not seek to protect the child. If protecting the child was their only consideration, these two conditions should have identical effects on the lateral clearance distance. The finding that the conditions do not have identical effects, suggests that, in real traffic, motorists balance any desire they might have to protect the child with situational factors pertaining to traffic volumes and the physical state of the street.

In addition to determining the safest way to transport a child by bicycle and determining whether drivers of motorized vehicles modify their overtaking behaviour when they observe a child being transported with the bicycle, this study also wanted to examine the safety of overtaking manoeuvres in general. Therefore the mean lateral clearance distance of the overtaking manoeuvres in this study was investigated and set off against the Belgian minimal lateral clearance distance norm of 100 cm (i.e. legal norm for the shared lane marking and considered as a safe norm for the bike lane). In general, and in almost all possible categories as well, the mean lateral clearance distance was greater than this norm, which can be considered as a reassuring finding. Unfortunately, 25.3% of all the overtaking manoeuvres felt under this norm of 100 cm and could therefore be considered as unsafe or in case of the shared lane marking as illegal. As mentioned before, it must be taken into account that different rules apply to the different types of cycling infrastructure (i.e. shared lane marking and bike lane). As a result, 24.4% of all overtaking manoeuvres on the shared lane marking were illegal, while the 26.2% maneuvers on the bike lane that were under 100cm could not be considered as illegal. However, due to the fact that the percentage of overtaking manoeuvres under 100cm did not differ between both types of cycling infrastructure.

Despite the majority of overtaking manoeuvres being greater than 100 cm, which are considered as safe, we can conclude that there exists a safety problem in the BCR with regard to overtaking manoeuvres. Especially when results indicate that in some specific categories the percentage of overtaking manoeuvres under 100cm was even higher, with the highest percentage (67.7%) recorded for 'cyclists without child' cycling on a bike lane during the morning peak. Since different rules apply in different countries it is hard to draw general conclusions. However, the number of 'illegal' and/or 'unsafe' overtaking manoeuvres can be compared with other studies. The results of this study (25.3%) are in line with studies from Spain and the United Kingdom, where respectively 36 and 34% of the overtaking manoeuvres were considered illegal/unsafe (Llorca et al., 2017, Walker et al., 2014). However, this contrasts with American results, where the number of illegal/unsafe overtaking manoeuvres is only between 0.5 and 3.9% (Chapman & Noyce, 2012; Kay, Savolainen, Gates, & Datta, 2014; Metha, Mehran, & Hellinga, 2015). A clear difference between Europe and America emerges here, which may be caused by a difference in cycling infrastructure and culture, but more studies are necessary to prove this difference effectively.

Policy makers may refer to these findings when developing new cycling policies, as overly close overtaking manoeuvres could discourage people from cycling more frequently or from cycling at all (Dozza et al., 2016; Mueller et al., 2015; Sanders, 2015). Worse, too close overtaking manoeuvres may lead to cycling crashes with serious injuries or fatal consequences (McCarthy & Gilbert, 1996; Stone & Broughton, 2003; Haworth et al., 2014). Acting more decisively against offenders may help to decrease the percentage of unsafe overtaking manoeuvres.

To our knowledge, no previous study compared an unseparated cycling lane to an on-street separated cycling lane. Mchale and Stewart (2014) already compared on-street separated coloured and uncoloured cycling lanes. Similar to the present study, the authors did not find a statistically relevant difference between both types of cycling lane, although, the same study did reveal a positive significant difference when comparing sites with uncoloured cycling lanes to sites without a cycling lane. Other studies found similar results when comparing overtaking manoeuvres in absence of a cycling lane with those case of an on-street separated cycling lane (Chapman & Noyce, 2012; Shackel & Parkin, 2014). These findings combined with the results of the present study, allows us to conclude that the presence of an on-street cycling lane leads to greater lateral clearance distances compared to a site without a cycling lane, but that the type of on-street cycling lane (i.e. separated or unseparated, and coloured or uncoloured) probably does not play an important role in the overtaking manoeuvres of motorized vehicles. The presence of a cycling lane in combination with the absence of a centreline (Shackel & Parkin, 2014) may lead to the safest overtaking manoeuvres in terms of lateral clearance distance, but future studies need to confirm this statement. Furthermore, it should be investigated whether drivers of motorized vehicles are aware of the different rules regarding to overtaking distance and cycling lanes, since there were no differences in both the mean lateral clearance distance and the number of overtaking manoeuvres under 100cm between the shared lane marking and bike lane.

However, a limitation of this study is the use of lateral clearance distance as the only major measure that is taken into account to determine the safety of an overtaking manoeuvre, which is actually too limited to draw more important conclusions. Other factors that influence the perceived and objective risk of an overtaking manoeuvre should be included in future studies, are the speed and angle of the motorized vehicle performing the overtaking manoeuvre (Llorca et al., 2017) and the presence of opposing traffic. Therefore, further investigations are required to better understand the overtaking behaviour of motorized vehicles when overtaking cyclists, as well as the safety of an overtaking manoeuvre itself. Finally, similar studies, but performed in other cities and/or countries, should make it possible to extrapolate results on the overtaking behaviour of motorized vehicles.

We must also acknowledge that previous studies have found considerable variability in driver behaviour around cyclists from one location to another (Olivier & Walter, 2013). As such, we must note that the BCR is a very specific study area, of which, furthermore, only one single type of road was used to perform the study. Caution should be taken when extrapolating the results of this study to the whole BCR as well as to outside the BCR, and replication of the effects of carrying a child in other locales would now be welcome.

5. Conclusion

Drivers of motorized vehicles adapt their overtaking behaviour when they overtake cyclists that are transporting a child, resulting in greater and therefore safer lateral clearance distances. However, this effect seems to be dependent on the time of the day and/or traffic density. In morning peak traffic hours, carrying a child in a bike seat had the lowest risk factor (greatest lateral clearance distance), but at other times of the day this effect was not present. At other times, a child trailer was needed to produce better driver behaviour. In general, the mean lateral clearance distance was on average greater than 100 cm – the minimum distance as prescribed by the Belgian Law - but at the same time a quarter of the overtaking manoeuvres was performed at less than 100 cm and therefore illegal. This finding allows us to conclude that still a lot needs to be done in order to improve cycling safety in the BCR in terms of overtaking behaviour of motorized vehicles. Researchers as well as policy makers may take these results into account when developing new studies or interventions to improve the cycling safety and enhance the cycling (for transport) prevalence.

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