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Green wave for cyclists: users’ perception and preferences

**Marco De Angelis[a], Arjan Stuiver[b], Federico Fraboni[a], Gabriele Prati[a],
Víctor Marín Puchades[a], Filippo Fassina[a], Dick de Waard[b], Luca Pietrantoni[a]**

Author Note
[a]Department of Psychology, University of Bologna, Bologna, Italy.
[b]Faculty of Behavioural and Social Sciences, University of Groningen, The Netherlands

Abstract

Several innovative measures in traffic control applied in Europe have successfully improved the comfort and safety of cycling, among which is the green waves for cyclists. Consecutive traffic lights are synchronised to create a green wave, increasing comfort and decreasing waiting times and related deliberate red-light running. This study focused on exploring the user acceptance of green wave systems and the user evaluation of six distinct interface designs (i.e. numeric-based countdown, dot-based vertical countdown, dot-based clockwise countdown, LED line, LED road surface, on-bike speed indicator). Results indicate a preference for three systems: numeric-based countdown, LED line and LED road surface. Results also show a significant influence of nationality on the evaluation of the interfaces. Based on our findings, we argue that the numeric-based countdown represents the most promising option for future adaptive green wave implementations. The outcomes of the present study represent a useful evidence and guidance for researchers, designers and decision makers in the field of green waves, mobility and traffic safety.

Key terms: *Green wave; user acceptance; user interface design***.**

1. Introduction

Traffic congestion causes delays which have further negative implications such as costs to the single person (e.g. increase of travel time), society (e.g. emissions, risk of accident) and business on a daily basis (e.g. delivery delays). In urban areas, congestion on roads can have an even wider impact considering that it is frequent that cars share the road with other road users such as pedestrians and cyclists.

To alleviate congestion, policy makers have focused their attention on improving public transport services and expanding infrastructure where they can intervene and innovate (Aldred, 2016). However, in urban areas it is often difficult to expand the road infrastructure due to residential areas adjacent to the existing roads. An alternative way to maintain or increase network performance is to improve traffic signal parameters to make a better use of the existing roads (Bravo et al., 2016).

With regard to traffic signals, the literature has moved from purely statistically based methods, over actuated traffic signals, to highly adaptive and cooperative methods which are able to predict and coherently respond to the dynamic aspects of traffic (Warberg et al., 2008). In the last years, developments in traffic light control plans increasingly emphasize their efficiency, environmental care, and safety for road users, thus potentially alleviating traffic congestion and reducing hazardous conflict and exhaust gases.

Nonetheless, studies on cyclists' behaviour at signalized intersections have demonstrated a high number of cyclists not complying with the traffic lights, particularly in a risk-taking way, that is, ignoring the red-light and travelling through the junction without stopping (Pai & Jou, 2014). Such behavior is especially common when cyclists ride alone (Fraboni et al., 2016). This is an important aspect to consider as many bicycle-vehicle crashes in urban areas occur at intersections (Prati et al., 2017). At most intersections cyclists are controlled by regular traffic signals, one way to improve safety and comfort at intersections is to install a bicycle-specific traffic signal (Thompson et al., 2013).

A traffic light control plan should facilitate a continuous traffic flow by reducing the number of stops for red whereas at the same time, discouraging cyclists from deliberate non-compliance crossing behaviour and thus preventing potentially dangerous conflicts between road users. An example of such system is the green wave that is a traffic light control plan where the green phase is synchronized between two or more traffic lights (on sequential intersections). Road users who pass through a green wave path will continue to receive green signals as they travel on the road with the correct speed, thus facilitating a continuous traffic flow in one main direction. This system has been initially developed for motorised traffic, but nowadays it is also being introduced to the cycling infrastructure.

2. Green waves for cyclists

The first green wave for cars was introduced in Berlin's Leipziger Strasse in 1926 (Vitaliev, 2016). In order to catch a green wave, road users needed to travel between two intersections with an appropriate speed to arrive at the next traffic light while it was in the green phase. The appropriate speed depended on the configuration of the green wave, dictated by the local situation.

A similar approach has recently been applied also in the cycling domain. For instance, in the Netherlands, Germany, and Denmark several innovative measures in traffic control have been implemented and have successfully improved the comfort and safety of cycling (Pucher & Buehler, 2008). Green waves for cyclists are usually created on bicycle lanes with dedicated traffic lights for cyclists. Consecutive traffic lights are synchronised to create a green wave.

The first green wave for cyclists, based in Copenhagen, has reduced both travel time going to and from the city centre along three main streets during peak hours by roughly 17% and the number of stops from six to less than one (City of Copenhagen, 2014).

A recent evolution of this concept is the introduction of an adaptive and cooperative traffic light plan that dynamically adapts the green wave to the cyclists' current travel speed. Using real time data it enables the alteration of the wave's direction, depending on the actual number of cyclists in each direction. This means that the number of green light phases for cyclists can be changed to give them priority over other traffic, for example, on rainy days when cyclists can accumulate at intersection.

This change of paradigm in the functioning of green waves, from fixed to adaptive, highlights the importance of communication between infrastructure and cyclists. In fact, infrastructure should be able to communicate to the cyclists what speed they should maintain in order to catch the next green wave. At the same time, cyclists should be able to readily understand the system to arrange a proper (re)action. The quality of this communication plays a crucial role in the effectiveness of green waves, particularly for the adaptive ones.

2.1.Countdown displays

Regarding the communication between infrastructure and cyclists, different types of interfaces are used as bicycle-specific traffic signals. However, limited research exists on road users' preferences for different traffic signals at green waves. In the present study, we attempt to fill this gap by investigating users' preferences on various types of infrastructure-human interfaces: traffic light countdown displays, on-bike displays and on-road surface signals.

Apart from the classic three-coloured traffic light interface, countdown signals are the most common addition, particularly in countries with developed cycling facilities and longer cycling tradition such as the Netherlands where numeric-based and dot-based countdowns are already widely used. Thus, countdown displays are a complementary feature of traditional traffic lights to improve users' behaviour at signalized crossings, as well as their safety (Lipovac et al., 2013). These displays add information about the remaining time of the current traffic light signal, leading to a reduction of the perceived waiting time (Antonides et al., 2002; Keegan & O'Mahony, 2003). According to Tromp et al. (2011), the countdown traffic signal reduces the uncertainty as road users know what to expect, which in turn decreases the likelihood of an irresponsible behaviour. In fact, previous studies concerning the impact of countdown displays have shown a reduction of deliberate red-light crossing behaviour among pedestrians (Keegan & O'Mahony, 2003; Lipovac et al., 2013).

Chiou and Chang (2010) investigated the effects of displays counting down to green or red (GSCD/RSCD). Results showed that counting down to green can increase safety by reducing late-stopping ratio, but at the same time it increases the potential risk of rear-end crashes. Counting down to red reduced the early start ratios, but only for a short period. However, it also had significant long-term effects on reducing start-up delay, saturated headway, and cumulative start-up delay. Therefore, red signal countdown shows a beneficial effect on intersection efficiency which is potentially larger than counting down to green.

In a systematic review, Fu et al. (2016) concluded that both a red signal countdown timer (RSCT) and a continuous countdown timer (CCT) enhance intersection capacity, although their actual impacts on intersection safety are unclear. Due to the limited and inconsistent evidence, the authors stated that it is not possible to recommend any type of countdown display to be installed at signalized intersections to improve safety and operational efficiency.

Despite the growing interests in the effects of countdown signals on user behaviour and intersection efficiency and safety, the driver's preferences and attitudes have remained underresearched. To our knowledge, only one study (Frank et al., 2015) analysed the user experience of countdown traffic light interfaces. The authors identified five Advanced Traffic Lights Interface designs (ATLI), taking inspiration from an existing concept “Eko” design by Stanković (2009). Participants stated that each ATLI represents a clear improvement to conventional traffic light designs. Although preferences varied depending on gender differences, the study indicates that traffic lights designs can be improved implying that the effectiveness and the users’ acceptance of new designs needs to be investigated.

2.2. In-vehicle and on-bike devices

A personal device or technology able to provide the users with information about traffic lights status directly on their vehicle or bicycle could represent a solution for effective infrastructure-human communication. To our knowledge, no such device has yet been studied or introduced in the market for bicycles. Nevertheless, similar technologies using the car dashboard, or a smartphone have been studied and designed for cars (Iglesias et al., 2008; Krause & Bengler, 2012; Thoma et al., 2008; Young, Birrell, & Stanton, 2011).

Other authors such as Avin et al. (2012) and Olaverri-Monreal et al. (2012), propose that physical traffic lights could be replaced by Virtual Traffic Lights that provide traffic light information directly to the driver through a Head-Up Display. Duivenvoorden et al. (2008) compared an in-vehicle display with a Variable Message Signs roadside system (i.e. traffic control signs which dynamically inform road users about the speed limit or lane use in response to traffic flow to overcome traffic congestion) as support for a green wave in terms of effects on driving behaviour, workload and user acceptance. Results showed that with the in-vehicle display participants drove slower, at a more constant speed, with fewer stops, and reported less mental workload.

Car manufacturers have also been developing in-vehicle technology on the dashboard display that informs the driver about the waiting time for the traffic light to turn green. A similar device could be installed on the handlebar of a bicycle, providing cyclists with information that helps to catch the green wave. For this reason, we included in our study an on-bike device able to inform the cyclists about the speed they need to maintain to reach the next traffic light in the green phase.

2.3.On-road surface signals

Recently, on-road surface horizontal traffic light signals have been introduced as an alternative concept of infrastructure-human communication. First trials of this new type of technology have been implemented in the cities such as Bodegraven in the Netherlands (Titcomb, 2017), Augsburg in Germany (Schmidt, 2016) and Copenhagen in Denmark (City of Copenhagen, 2014).

In Augsburg, road surface LED lights positioned at the pedestrian crossing were installed to help smartphone users crossing the road safely. In Copenhagen, the interface consists of LED lights positioned next to the cycling lane that indicate the speed that cyclists should maintain to catch the green wave.

2.4. Present study

So far, only a limited research has been dedicated to exploring users’ preference and acceptance of the new types of infrastructure Human-Machine Interfaces (HMI). To our knowledge, no study has yet compared users’ attitudes towards different HMIs. The present study attempts to address this issue by evaluating different HMI designs in order to identify which has the potential to work best for the cyclists.

The main concept was to elaborate different interfaces and rate them according to users' preferences and acceptance. The prototypical designs developed for this research follow the three categories that have been considered so far (i.e. countdown, on road surface, on-bike device). They cover a myriad of existing designs, and are the outcome of the research on existing designs and discussion between the authors and experts in the field. We acknowledge that there could be issues related to systems' costs and feasibility, however, these evaluations are beyond the scope of the present study.

The following six green wave systems were selected:

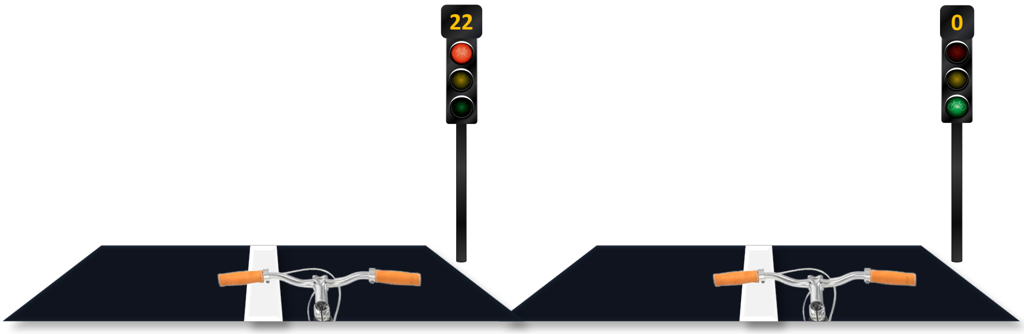

Fig. 1. The "numeric-based countdown" systems

The "numeric-based countdown" is the most common countdown signal design and it has already been implemented at intersections in various countries. It consists in a traffic light display design (Fig. 1) in which the cyclist is informed about the remaining time in seconds before the light turns green. This way, cyclists can estimate the speed they need to reach the intersection in time for the green light.

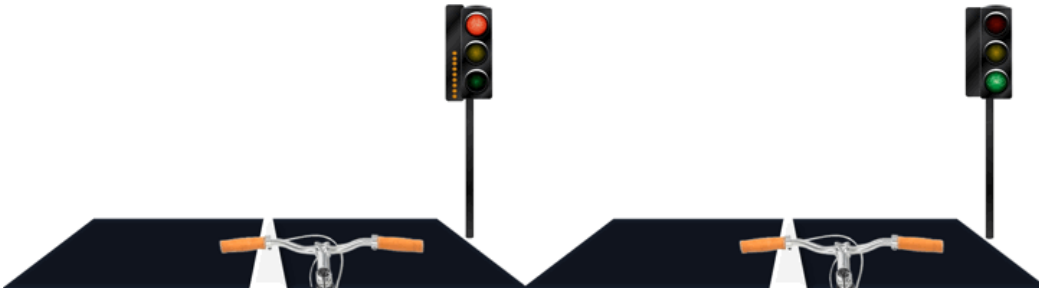

Fig. 2. The "dot-based vertical countdown" systems

The "dot-based vertical countdown" system (Fig. 2) is a traffic light display design in which the cyclist is informed about the remaining time before the light turns green through an hourglass-based concept. The dots disappear as the waiting time is ending. Cyclists will not be aware of the exact seconds remaining, but they will have an idea of the remaining time before the light turns green based on the number of dots still illuminated, and the speed at which the dot bar length is reduced. This type of design is already in use in the Netherlands.

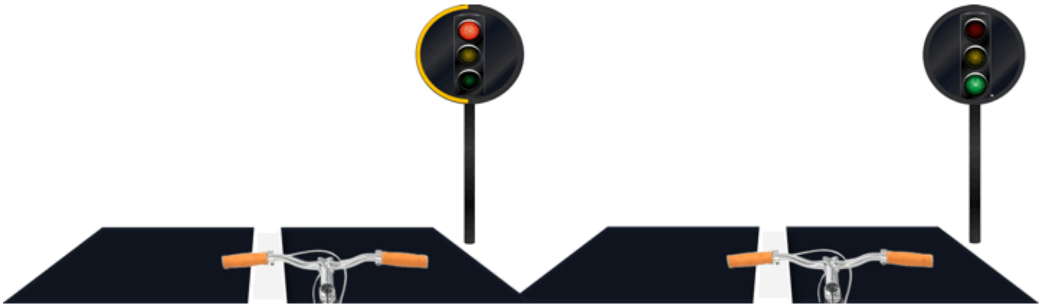

Fig. 3. The “dot-based clockwise countdown”

The “dot-based clockwise countdown” (Fig. 3) system is a traffic light display design quite similar to the previous one. The only difference is that instead of a series of vertical dots that progressively turn off as the green phase is drawing closer, in this concept, the hourglass-based approach has the shape of a circular clock line.

Fig. 4. The “LED line” system

The “LED line” system (Fig. 4) is an on-road surface interface in which the cyclist is informed about the “right” speed to maintain to catch the green wave by a green LED-line located on the side of the cycling lane. Following the speed of the green light will guide the cyclist through the green traffic signal ahead. The concept of the “LED line” has been taken from the prototype used in Copenhagen, described in the previous section.

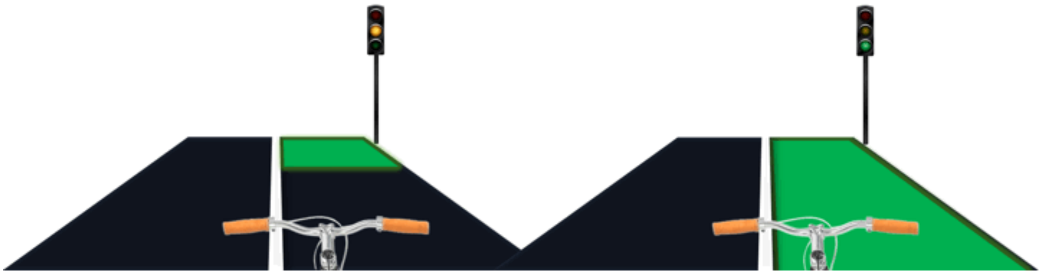

Fig. 5. The “LED road surface” system

The “LED road surface” (Fig. 5) system is an on-road surface design that can be considered as an evolution of the previous one (i.e. the “LED-line system”). In this case, instead of a LED line installed next to the cycling lane, it is the whole cycling lane that works as a cyclist’s speed regulator. As described before, following the speed of the green light lane will guide the cyclist through the green traffic signal ahead.

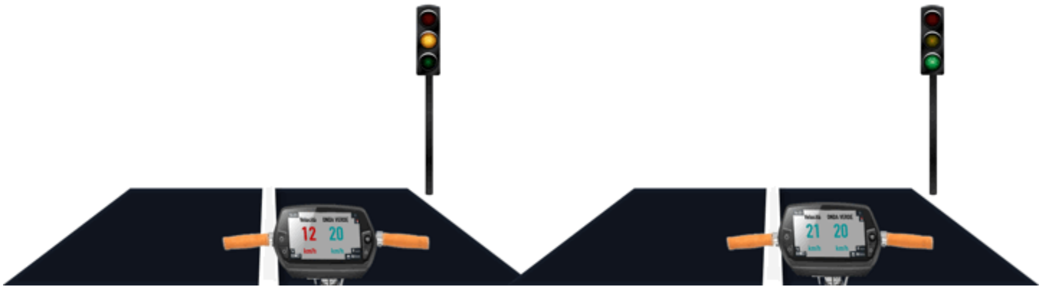

Fig. 6. - The “on-bike speed indicator” system

The “on-bike speed indicator” system (Fig. 6) is based on infrastructure-to-bike communication. The infrastructure system detects the cyclist’s speed and, in turn, sends a dedicated signal to the on-bike system which informs the cyclist about the speed needed to catch the green phase once approaching the intersection. Cyclists approaching the signalized intersection during the red phase can decide whether to increase their speed to enter the intersection or to slow down and make a stop. The speed indicator and the LED-line and LED road surface systems provide implicit information about both the time to green and red, in other words, cyclists can behave based on an estimation (e.g. distance from the LED-line, speed-gap between current and expected speed) of the time left to catch the green light.

Considering the development of adaptive and cooperative traffic lights (e.g. green wave) and the potential benefits of the green wave for cyclists’ safety and traffic flow, the present study focused on exploring the user acceptance of the green wave concept and the user evaluation of several traffic lights interfaces to identify the most suitable design. Further, we conducted the study in two countries with a different cycling culture (Italy and the Netherlands) to explore any national differences in participants’ preferences and acceptance of the HMI designs. There is evidence that for the acceptance of new technologies familiarity plays a central role (e.g. Chang 2010). For instance, Dutch cyclists are mostly familiar with the concept of cyclists’ countdown traffic light. Therefore, in the present study we expected differences in terms of users’ evaluation in what we could refer to as ‘bicycle culture’ (i.e. effects of nationality) as well as to take cycling commuting percentage into account.

Apart from the countdown displays (i.e. dot-based vertical, dot-based clockwise, numeric-based countdown systems), the other systems represent an innovative solution in the infrastructure-cyclist communication shifting the paradigm from a “temporal” cognitive process to a “spatial/position” evaluation. In other words, cyclists should be able to understand what to do to catch the green light by “merely” following the position of the LED-based HMIs or by covering the gap between their current speed and the optimal one. As such, they do not need to calculate their own optimal speed by the number of dots and the speed at which the dot bar length is shortening as is the case of the countdown displays. Differences between the other HMIs are expected since Thoma et al. (2007) found that the countdown HMI performed better due to its predictability and independence from the vehicle’s speed and position, which is not the case with the on-bike system and the LED-based HMIs.

The study objectives are addressed by investigating the following research question:

- How are green wave interfaces evaluated and accepted and how the evaluations and preferences vary between participants from countries with different bicycle culture and a different cycling commuting rate?

3. Method

3.1.Study Considerations

The present study focuses on Italy and the Netherlands as case countries for different reason. First of all, according to the Eurobarometer 422 survey (Directorate-General for Communication of the European Commission, 2015), these countries differ significantly in terms of the use of bicycle as the main mode of transport. Specifically, while only the 6% of Italian participants stated that they use “bicycle” as their principal mode of transport compared to 36% of Dutch participants.

Secondly, the Netherlands have been at the forefront of policies to make cycling safe and popular and as such, they can be considered an exemplar “cycle-oriented culture” (Pucher et al., 2008). Italy can be seen as an emerging cycling country with an “automobile-oriented culture”. The rate of motorization in Italian cities is rather high (603 cars/1000 inhabitants; Istat, 2015) and 80.1% of the trips were made by car (in the EU this amounts 81.9%; European Union, 2016).

Finally, these two countries differ also in terms of the level and quality of bicycle infrastructure (Fishman, Schepers, & Kamphuis, 2015; Pucher et al., 2011). Some of the green wave interfaces concepts, specifically the countdown traffic light displays, are already well known by Dutch cyclists whereas in Italy there is still a lack of infrastructure and effective cycling policies (ECF, 2016).

3.2.Procedure

We asked participants to evaluate the six different green wave systems with the different display designs as described in section 2.4. For this, six short video clips using GIFs were created. Furthermore, to maintain consistency throughout the questionnaire and to avoid any kind of bias on user’s evaluation, each clip was simultaneously representing both the scenario in which the cyclist is approaching the traffic light during the red phase and the scenario where the cyclist finally gets the green wave. At the start of the experiment, all participants filled in a general demographic questionnaire and provided informed consent.

3.3. Participants

A total of 450 Italian (*n*= 313, 69.6%) and Dutch (n= 137, 30.4%) young adult participants filled in the questionnaire, all of them were students. For participation they either received credits or had a chance to win a voucher. While some students were recruited through a student participant pool which gave credits in return for their active participation, others were recruited through a paid participant pool where they could win one of four vouchers worth € 15. Table 1 shows the frequencies of participants’ gender, age, and bicycle commuting for the entire sample, as well as for each country. The majority of the Dutch participants (65.7%) used the bicycle to commute between 75 and a 100% of the time, whereas the majority (84.3%) of the Italians used it 25% of the time or less for commuting.

Table 1
Age, Gender, and Bicycle Commuting Frequencies and Percentages per Country

	Total (*N*=450)		**Italian (*n*=313)**		**Dutch (*n*=137)**	
Gender						
Female	289	(64.2%)	225	(71.9%)	64	(46.7%)
Male	142	(31.6%)	88	(28.1%)	54	(39.4%)
Missing	19	(4.2%)	0	(0.0%)	19	(13.9%)
Age						

18-24	359	(79.8%)	256	(81.8%)	103	(75.2%)
25-34	59	(13.1%)	45	(14.4%)	14	(10.2%)
35-44	5	(1.1%)	5	(1.6%)	0	(0.0%)
45-54	7	(1.6%)	5	(1.6%)	2	(1.5%)
65-74	2	(0.4%)	2	(0.6%)	0	(0.0%)
Missing	18	(4.0%)	0	(0.0%)	18	(13.1%)
Bicycle Commuting						
0 – 25%	285	(63.3%)	264	(84.3%)	21	(15.3%)
26 – 50%	26	(5.8%)	17	(5.4%)	9	(6.6%)
51 – 75%	21	(4.7%)	9	(2.9%)	12	(8.8%)
76 – 100%	112	(24.9%)	22	(7.0%)	90	(65.7%)
Missing	6	(1.3%)	1	(0.3%)	5	(3.6%)

3.4. Measures

We measured participants' perception of nine attributes of the technology: ease of use, intuitiveness, understanding/comprehensiveness, usefulness, reliability, comfort increase, safety increase, travel time reduction (i.e., to the hypothetical destination), and reduction in probability of jumping the red-light, that is to reduce the chance to intentionally commit a non-compliant crossing behaviour. The attributes presence in each one of the HMI concepts were rated using a 4-point Likert scale (1 = *Not at all*, 2 = *Not much*, 3 = *Much*, 4 = *Very much*).

The attributes were distributed into two overarching questions and participants answered to each one of them. The wording of the first one was "*Looking at the signage in the image above, do you think it is: (1) Easy to use; (2) Intuitive; (3) Comprehensible; (4) Useful; and (5) Reliable*."

The second question was "*If while riding your bike you find yourself at an intersection with this signage, to what extent do you think it could: (6) increase your riding comfort; (7) increase your cycling safety; (8) reduce the time required to get to the destination; (9) reduce the probability you will skip the red-light.*" Each attribute appeared on a new line and participants could assign a score to each one of the attributes besides these.

To evaluate the factor structure of participants' perception of nine attributes of the technology, we performed an exploratory factor analysis. After having assessed each one of the six HMI concepts, participants were asked to identify which one was their preferred HMI.

3.5. Statistical Analysis

The collected data were analysed with a mixed design analysis of variance (ANOVA) using IBM SPSS 25. The chosen level of statistical significance was $p < .05$. Univariate differences were assessed with chi-square tests. We examined the main effects of gender (between-subjects: female, male), nationality (between-subjects: Dutch, Italian), bicycle commuting percentage (between-subjects: those commuting more than 50 percent of the time versus those commuting less than 50 percent of the time), and attributes in the evaluation of each HMI (within-subjects: easy to use, intuitive, comprehensible, useful, reliable, increases comfort, increases safety, reduces travel time, and reduces likelihood red-light running) and their interactions. Mauchly's W test indicated that the assumption of sphericity had been violated, therefore we used multivariate test statistics (MANOVA). Based on recommendations by Tabachnick and Fidell (2013) for accommodating violations of sphericity, we have applied the Huynh and Feldt's correction to verify that results were unchanged when this correction for violation of sphericity was applied. Bonferroni adjustments for multiple comparisons were applied for the post hoc pairwise comparisons.

4. Results

Parallel analysis revealed two factors which correspond to the two overarching questions presented above. Specifically, the first factor was named "Evaluation of the HMI" and included the following attributes: ease of use, intuitiveness, understanding/comprehensiveness, usefulness, and reliability. The second factor included comfort increase, safety increase, time reduction (i.e., to the hypothetical destination) and reduction in the probability of skipping the red-light and was named "Impact of HMI on riding".

Levene's test indicated that the assumption of homogeneity of variance was not violated. The mixed-design ANOVA revealed a significant main effect of nationality on Impact of HMI on riding, $F(1, 426) = 8.33$, $p = .004$, $\eta^2 = .02$. Post-hoc pairwise comparisons revealed that participants from Italy ($M = 2.82$, $SE = 0.04$) were more likely to agree with the items of Impact of HMI on riding compared to participants from The Netherlands ($M = 2.62$, $SE = 0.05$), $p = .004$. The main effect of nationality on Evaluation of the HMI was not significant, $F(1, 426) = 0.24$, $p = .625$, $\eta^2 = .00$. There was no significant main effect of gender on both Evaluation of the HMI, $F(1, 426) = 1.25$, $p = .265$, $\eta^2 = .00$, and on Impact of HMI on riding, $F(1, 426) = 0.11$, $p = .745$, $\eta^2 = .00$. Also, there was no significant main effect of bicycle commuting percentage on both Evaluation of the HMI, $F(1, 426) = 0.05$, $p = .821$, $\eta^2 = .00$, and on Impact of HMI on riding, $F(1, 426) = 1.12$, $p = .290$, $\eta^2 = .00$.

There was a significant main effect of type of HMI on both Evaluation of the HMI, $F(1, 426) = 58.51$, $p < .001$, $\eta^2 = .12$, and on Impact of HMI on riding, $F(1, 426) = 50.53$, $p < .001$, $\eta^2 = .11$. Figures 7 and 8 show post-hoc pairwise comparisons following repeated measures analysis of variance for Evaluation of the HMI and Impact of HMI on riding, respectively. The mean scores on Evaluation of the HMI for numeric-based countdown, LED line, and LED road surface were higher than those for the other HMIs. Moreover, the mean scores for the on-bike speed indicator were the lowest. A similar pattern emerged for the mean scores on Impact of HMI on riding for each of the six HMI. It should be noted, however, that the mean score on Impact of HMI on riding for the numeric-based countdown was significantly lower than that for LED road surface.

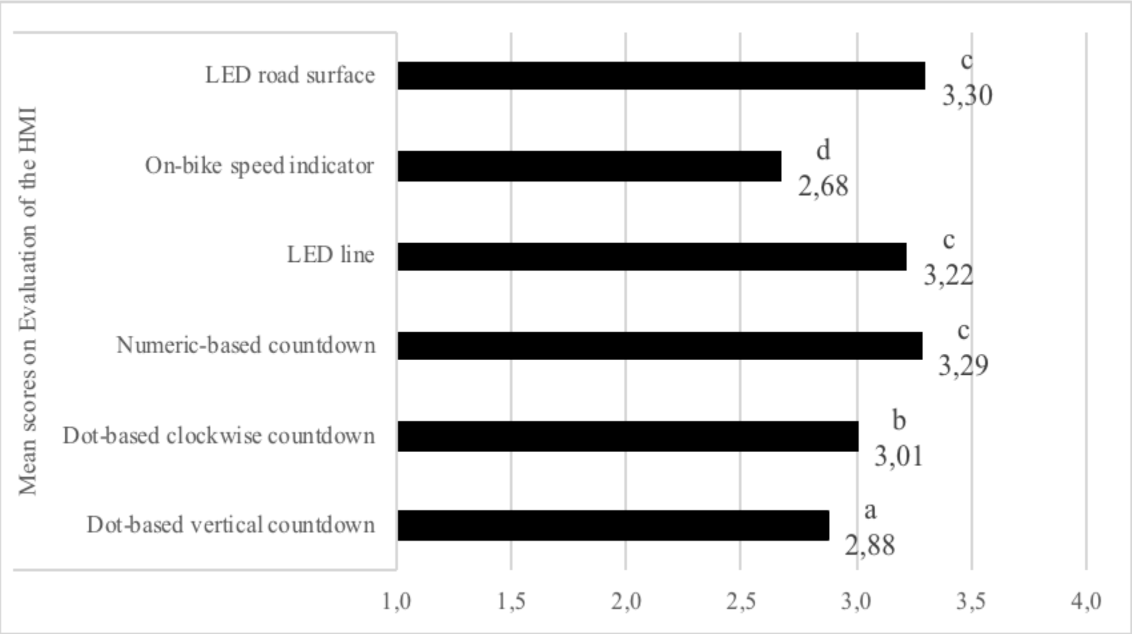

Fig. 7. Mean scores on Evaluation of the HMI for each of the six HMI.
Note. Bars sharing the same letter do not differ significantly from each other.

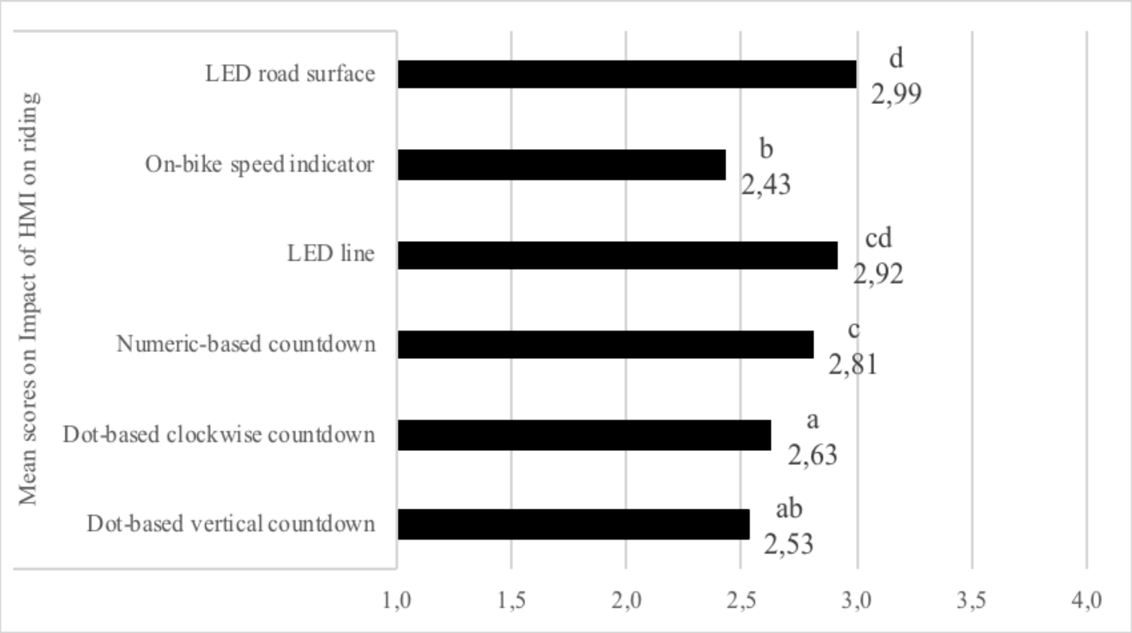

Fig. 8. Mean scores on Impact of HMI on riding for each of the six HMI.
Note. Bars sharing the same letter do not differ significantly from each other.

Results of repeated-measures analysis of variance are presented in Table 2. We found a significant effect for both Evaluation of the HMI and Impact of HMI on riding. In addition, the interactions between gender or bicycle commuting percentage and both Evaluation of the HMI and Impact of HMI on riding were not significant. We found a significant interaction between nationality and both Evaluation of the HMI and Impact of HMI on riding.

Table 2
Repeated Measures Analysis of Variance of the Attributes.

Effect	*MS*	*df*	*F*	*p*	η^2
Evaluation of the HMI	19.86	5	58.51	< .001	0.12
Impact of HMI on riding	15.75	5	50.53	< .001	0.11
Nationality × Evaluation of the HMI	2.70	5	7.94	< .001	0.02
Nationality × Impact of HMI on riding	1.90	5	6.11	< .001	0.01
Gender × Evaluation of the HMI	0.06	5	0.18	= .971	0.00
Gender × Impact of HMI on riding	0.11	5	0.34	= .888	0.00
Bicycle commuting percentage × Evaluation of the HMI	0.27	5	0.78	= .562	0.00
Bicycle commuting percentage × Impact of HMI on riding	0.19	5	0.62	= .686	0.00

Note. Results did not change when the Huynh and Feldt correction for violation of sphericity was applied.

Figures 9 and 10 show results from post-hoc pairwise comparisons for Evaluation of the HMI and Impact of HMI on riding, respectively. Italian participants reported higher scores on Evaluation of the HMI for the on-bike speed indicator, while Dutch participants reported higher scores on Evaluation of the HMI for the dot-based vertical countdown. In addition, Italian participants reported higher scores on Impact of HMI on riding for three HMIs: numeric-based countdown, on-bike speed indicator, and LED road surface.

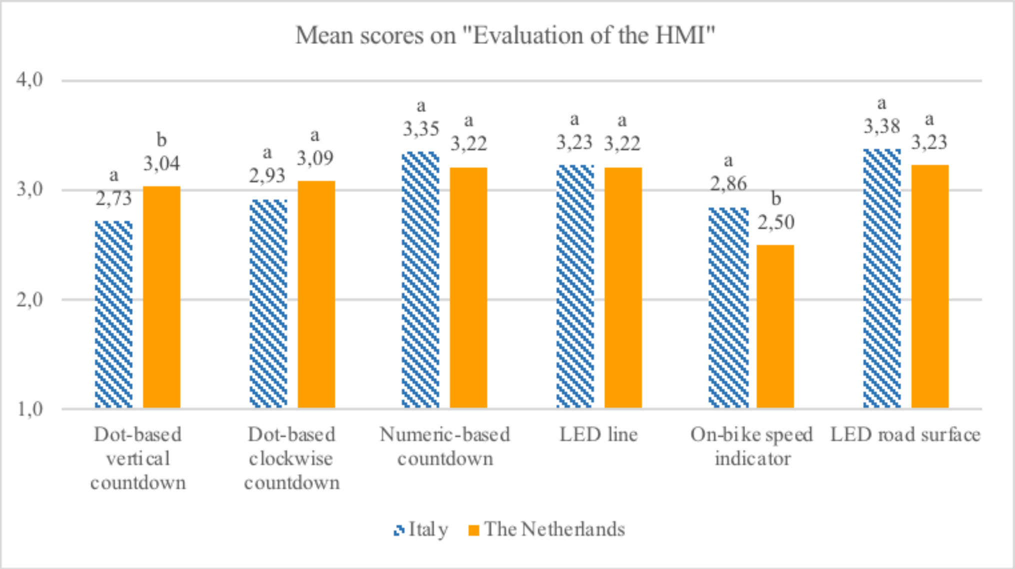

Fig. 9. Mean scores of Italian and Dutch participants on Evaluation of the HMI for each of the six HMI.

Note. Bars sharing the same letter do not differ significantly from each other.

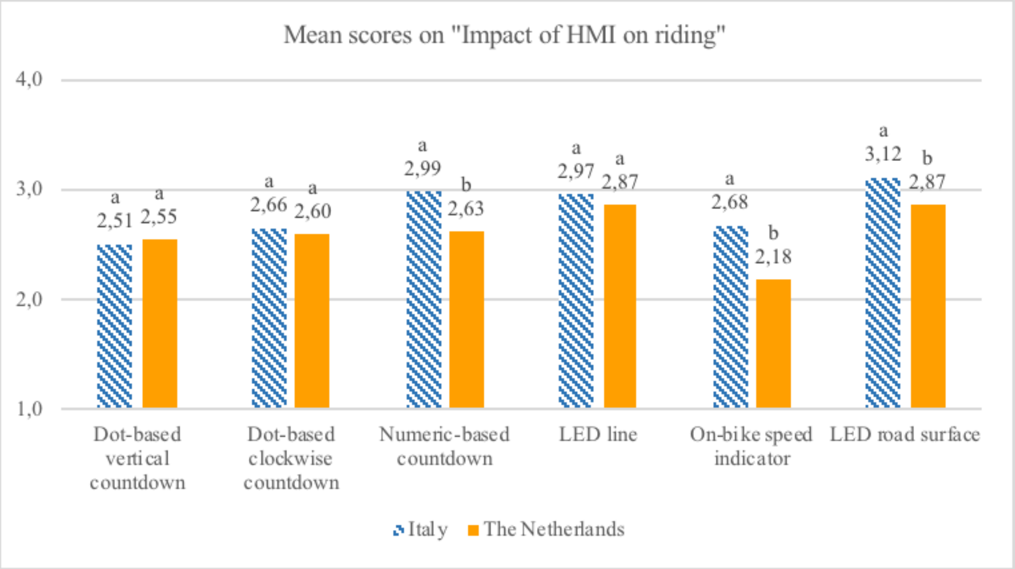

Fig. 10. Mean scores of Italian and Dutch participants on Impact of HMI on riding for each of the six HMI.

Note. Bars sharing the same letter do not differ significantly from each other.

These results were confirmed by those related to the most preferred design. In fact, the most preferred HMIs were: LED road surface (the most preferred by Italian participants), LED line (the most preferred by Dutch participants), and numeric-based countdown. There were no gender differences in participants' ratings of the most preferred HMI ($\chi^2(5) = 3.94$, $p = .558$).

Nevertheless, as shown in Figure 11, Italian and Dutch participants reported different ratings of the most preferred HMI, ($\chi^2(5) = 29.36$, $p < .001$). To help uncover differences between Italian and Dutch participants we computed pairwise comparisons of column proportions using the Bonferroni correction. We found significant differences in the preference for numeric-based countdown and dot-based vertical countdown. With regard to the numeric-based countdown, Italian participants expressed higher preference compared to their Dutch counterparts (p <.05), while Dutch participants were more likely to indicate the dot-based vertical countdown as the most preferred HMI (p <.05).

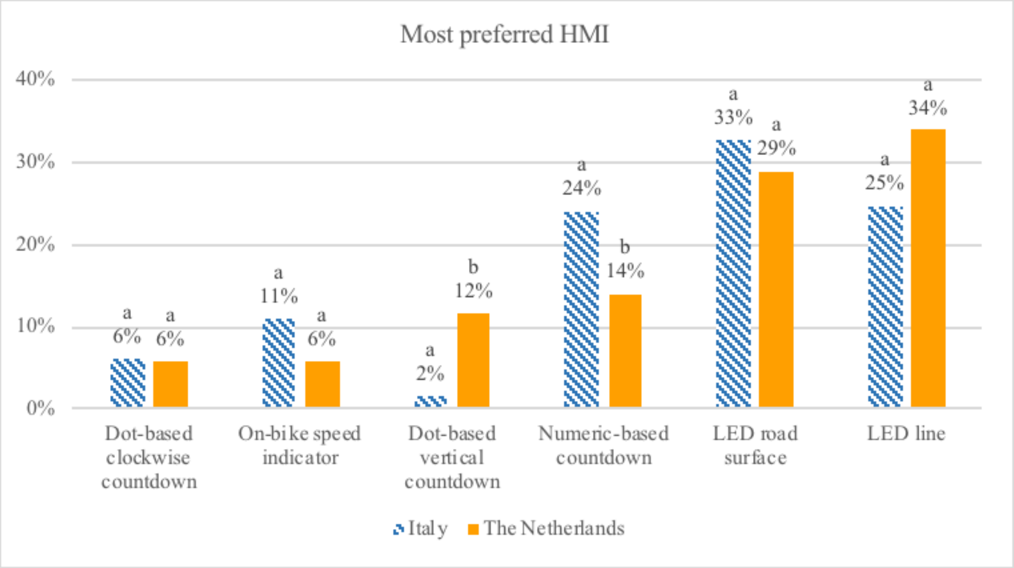

Fig. 11. Italian and Dutch participants' most preferred HMI.
Note. Bars sharing the same letter do not differ significantly from each other.

Finally, the percentage of bicycle commuting was associated with different ratings of the most preferred HMI, $\chi^2(5) = 11.82$, $p = .037$. Specifically, among participants commuting more than 50 percent of the time, the "most preferred HMI" was LED line, while among those commuting less than 50 percent of the time the "most preferred HMI" was LED road surface (Fig. 12).

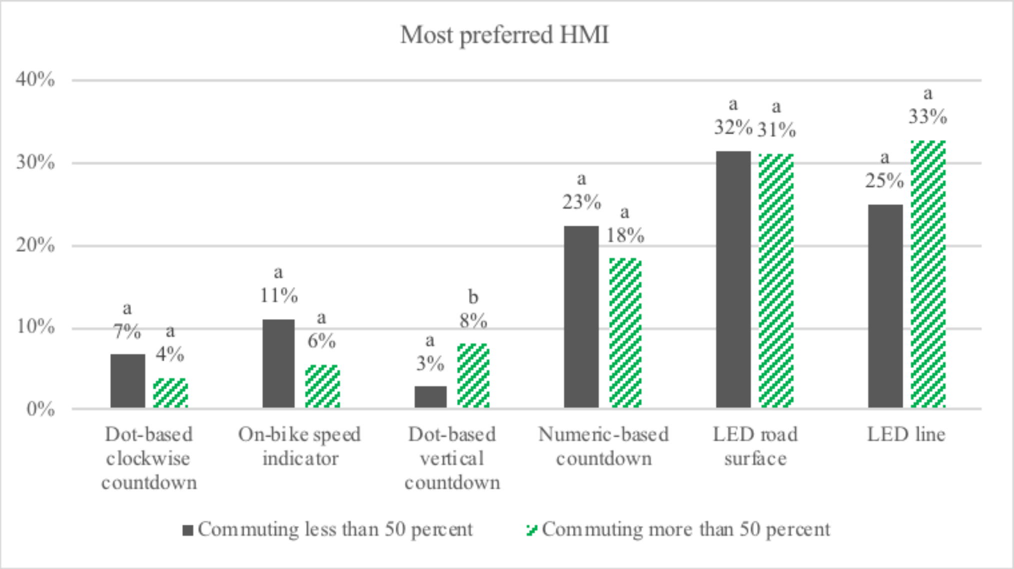

Fig. 12. Ratings of most preferred HMI according to the percentage of bicycle commuting.

Note. Bars sharing the same letter do not differ significantly from each other.

5. Discussion

The purpose of the study was to investigate users' preferences of different interface designs in Italy and in the Netherlands. Several attributes of the interfaces have been evaluated to assess cyclists' acceptance and beliefs about them. Considering the present research question, the analysis revealed differences in terms of users' perception as well as significant interaction between nationality and evaluation of the interfaces.

Results showed that nationality seems to affect the attributes evaluation for the specific HMIs. The major result is that Dutch participants, compared to Italian, tend to give a significantly higher evaluation of the dot-based countdown on almost all the attributes. This result is not unexpected since the dot-based countdown display is already widely used in the Netherlands. Here, the familiarity of the design could play a twofold role. First, according to Zajonc (1968), the mere exposure of individuals to a repeated stimulus makes them rate that stimulus positively than unknown ones. Second, previous experience, both with the system or related systems, has been proven to foster acceptance of technology (e.g. Holzinger et al., 2011) and automation (e.g. Rödel et al., 2014). As pointed out by Ghazizadeh et al. (2012), the previous experience with the system could be a crucial factor in building trust toward the system that, in turn, is a predictor of acceptance of the technology. Previous experience could thus explain the differences between the sub-samples, but not the overall acceptance of the design. That is, in fact, a multi-facet construct in which trust (and previous experience) is just one of the determinants.

Furthermore, Italian participants, compared to Dutch, reported higher ratings for the "Impact of HMI on riding" factor which comprises HMI aspects on safety, travel time, reduced chance of red-light running and comfort. While Italy can be considered as an emerging cycling country, where the recent increase in the number of cyclists has not yet been followed by the development of appropriate cycling facilities, the Netherlands is an established cycling country with a well-developed cycling infrastructure (e.g. Pucher et al., 2011). In addition, cyclists are seen (and perceive themselves) as minority road users, especially in emerging cycling countries (Prati et al., 2017).

Differences between the two countries in what we could refer to bicycle culture may affect perceptions and attitudes towards advanced cycling facilities and, more specifically, the idea of synchronizing traffic signals to provide a green light for a flow of cyclists. Therefore, regardless of the specific design characteristics, green waves in separated cycle lanes could represent a major improvement for safety, travel time and deliberate non-compliant red-light behaviour in emerging cycling countries compared to established cycling countries. In fact, Dutch cyclists, although not experienced with the green wave for cyclists, are already familiar with the concept of cyclists' countdown traffic light (i.e., dot-based countdown), meaning that they are used to receiving information about the next green phase. For these reasons, Dutch cyclists may tend to have higher expectations about the impact of green waves. On the other hand, an improvement in the quality of infrastructure-to-cyclist communication (e.g. a better type of HMI) could represent an improvement in the comfort perceived by the users. Fraboni et al. (2016) showed that the rate of red-light running is frequent in Italy in comparison with other countries. Again, the two different "starting points" could have played a role in shaping the expectations about the reduction of deliberate red-light running likelihood.

No significant effect of gender in the evaluations of the systems' attributes was found, a result that differs from the findings by Frank et al. (2015), in which a small sample of males and females (N = 12) rated the HMIs differently. It is plausible that considering the small size of their sample, results could have been biased by few extreme scoring individuals thus underlining gender differences in user's acceptance. In contrast with Frank et al. (2015), in our study the higher sample size could have reduced the impact of gender on the evaluations of the six HMIs. Furthermore, the distinctive approaches adopted (lab environment vs online survey) and the heterogeneity of HMI concepts could have affect users' evaluation, thus making gender differences more evident in the first study.

Results point to three systems that scored significantly above the others in almost all the attributes: numeric-based countdown, LED line and LED road surface. These systems received significantly higher ratings in ease of use, usefulness, reliability, comfort and safety increase. In particular, the two LED systems scored even above the numeric-based countdown in travel time and deliberate red-light running reduction attributes. Moreover, these three systems have also been indicated as the most preferred ones by both the sub-samples, even if not in the exact same order. These results indicate that LED line, LED road surface, and numeric-based countdown would be the most accepted designs.

Although the information conveyed by each system is similar, it might have to be extracted differently by the users (e.g. based on time, speed or distance). Both LED systems represent an innovative solution in the infrastructure-cyclist communication shifting the paradigm from "temporal" cognitive processes, typical of the countdown systems, to a "spatial/position" evaluation in which the cyclist does not have to make complex calculations about the time still available, the optimal speed to maintain/reach and the distance to cover but has to "simply" reach and maintain a certain position to catch the green light. In fact, the LED segments could facilitate cyclists' creation of an effective mental model of green wave functioning. Owning an effective mental model can bring a twofold advantage. On one hand, it helps to reduce the cognitive workload by improving the cyclists' ability to understand current and predict future system behaviour (ISO 100075, 1991). On the other hand, it increases the user experience, helped by the affordance of the green segments which might help the user to readily understand the system, the surrounding environment and in turn, increase the users' pleasure of cycling (Norman, 2004, 2013).

We acknowledge the costs and feasibility problems related to the LED systems. In fact, providing long sections of cycling lanes with continuous LED lights could raise problems in implementation and maintenance costs. This is particularly true for the LED road surface. For this reason, the numeric-based countdown option could represent an optimal compromise between users' evaluation and feasibility. Compared to the others, this system could facilitate the creation of a green wave functioning mental model. In fact, the numeric-based countdown could trigger the activation of a model based on the temporal requirements needed by the green wave to effectively function. For the mental model to be effective, it does not have to be an exact representation of how the system works as long as it helps the user understand so (Norman, 2013).

5.1.Limitations

There are some further limitations of the present study. First, participants were asked to evaluate the HMIs through imagination in cases where the system does not exist or has not been experienced (e.g. LED road surface), and by actual experience in the rest of the cases (e.g. potentially the dot-based countdown for the Dutch sub-sample). This difference in experience may have influenced the results, as explained earlier. Nonetheless, investigating users' evaluation of not yet existing interfaces was already successfully applied by Meschtscherjakov et al. (2009) and is commonly used in the field of autonomous vehicles.

A second limitation is the sampling method, which does not allow full generalization of the findings. This study used a sample composed of university students from both Italy and the Netherlands. Future research should include a more representative sample of cyclists considering a wider range of age, geographical origin, professional status and bicycle usage. Third, evaluations may have suffered from lack of understanding due to the low-realism of the scenarios. Further investigations could consider different techniques of image representation such as high-reality 3D videos, and virtual and augmented reality to improve the quality of the experience, but still make it more affordable than real prototyping (Lawson, Herriotts, Malcolm, Gabrecht, & Hermawati; 2015; Lawson, Salanitri, & Waterfield, 2016).

5.2. Study implications and Future Directions

The results of the present study are significant for a variety of stakeholders. This research is firstly useful for designers of traffic signals, who can use it as an input for designing more user-centred and effective interfaces. Secondly, the results are relevant for decision makers such as local governments, urban planners, road authorities, traffic regime managers, i.e., for those who should make decisions on green waves for cyclists.

The results highlighted the importance of addressing users' preferences and acceptance of different interfaces for green waves, showing how different designs lead to different evaluations and perceived benefits, and finally to different degrees of acceptance. Bearing this in mind while making decisions about the implementation of green waves will help decision makers put the human being at the centre and focus not only on strategical and technical aspects but also on social ones, thus advancing in the needs of users in transport (Editorial, 2015). As pointed out by several road safety experts, a technological system, even if technically perfect, when not accepted by end users will fail in achieving its purposes (Najm et al., 2006; van der Laan et al., 1997). This research provides data on which to lay upon future evidence and practices.

It is advisable that to test the designs investigated in the present study in realistic conditions, including simulator and field tests. Taking different experimental conditions into account will give the chance to assess behavioural measures (e.g. speed, position, gaze behaviour, success rate, etc.) and behaviour change (with pre and post measurement). Another important issue to evaluate in a real environment is the visibility of the interfaces in various light conditions and from various distances. Moreover, given the different characteristics of each of the HMIs, studies should take into account how people with different sight conditions (e.g. far-sightedness, glaucoma) respond to them, as well as at different speeds and environmental conditions.

6. Conclusion

In conclusion, the aim of the present study was to assess users' evaluation and acceptance of different interfaces for cyclists' green waves. Results showed how, despite differences in the evaluation of HMIs in the two countries, that the numeric-based countdown, the LED line, and the LED road surface were the best-rated designs on most attributes and were also rated as the most preferred ones. Due to higher feasibility, the numeric-based countdown probably represents the most promising option for future adaptive green wave implementations. Within this perspective, the implementation of a technology that can be accepted by different groups of cyclists and different cycling cultures should be encouraged to further support designers and decision makers in the field of mobility and cycling safety measures.

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