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Published in IET Intelligent Transport Systems
Received on 29th July 2011
Revised on 7th November 2011
doi: 10.1049/iet-its.2011.0130

ISSN 1751-956X

Intelligent intersection support for powered two-wheeled riders: a human factors perspective

V. Huth[1] *R. Lot*[2] *F. Biral*[3] *S. Rota*[2]

[1]*Université de Lyon, IFSTTAR (LESCOT), 25 Avenue François Mitterand, Case 24, 69675 Bron, France*
[2]*Department of Industrial Engineering, University of Padova, Via Venezia, 1, 35131 Padova, Italy*
[3]*Department of Mechanical and Structural Engineering, University of Trento, Via Mesiano, 77, 38050 Trento, Italy*
E-mail: veronique.huth@ifsttar.fr

Abstract: Given that intersections represent particularly hazardous situations for riders of powered two wheelers, an intelligent intersection support system has been developed. This system provides a warning whenever the rider approaches an intersection at an unsafe speed. This study reports the results of a pilot evaluation of the system from a human factors perspective. In a motorcycle simulator, the system was tested with two alternative rider interfaces: a force feedback throttle and a haptic glove. Riding with the system versions was compared with riding without support. Although the number of potentially critical situations did not decrease when using the system, the results confirm that the warnings by both system versions led to a significantly reduced approach speed to the intersection, at least in a rural scenario. The riders perceived more benefits from riding with the intersection support when the warning was transmitted by the haptic glove than when they received the alert by the force feedback throttle. Accordingly, the acceptance of the latter system version was much lower. Relevant factors for the safety potential of the intersection support system are discussed and further research needs are deduced from the limitations of the study.

1 Introduction

Riders of powered two wheelers are a particularly vulnerable road user group. They represent about 15% of all traffic fatalities in Europe [1], but make up a much lower percentage of all road users (2% according to the CARE 2006 survey [2]). The consequences of a crash are likely to be more severe for riders than for passengers of other vehicles since they are much less protected and can easily be thrown off from their vehicle [3, 4].

One of the most risk-encumbered settings for users of powered two wheelers is the intersection situation. Front-side crashes at road junctions have been identified as the second most representative scenario for motorcycle crashes after single vehicle crashes where the rider loses control in a curve [5]. They often result from conflicts in directional movements with high-speed differences and are particularly injurious [6, 7]. These right-of-way violations are mainly preceded by inattentiveness, driving errors and risky driving [5]. In up to two-thirds of the cases, the driver of another vehicle infringes upon the rider's right of way, getting into the trajectory of the approaching powered two wheeler [8–11]. Two types of human failure underlie these crashes: detection errors and decision errors. On the one hand, powered two wheelers are often overlooked by drivers [12, 13]. The 'looked-but-failed-to-see' error [14, 15] is driven both by the stimulus characteristics (e.g. high spatial frequency) of the powered two wheeler in the driving environment [16–19] and by the expectations of the drivers, which often do not include approaching powered two wheelers and lead to inattentiveness with regard to this vulnerable road user group [20]. On the other hand, drivers tend to overestimate the time gap until the motorcycle reaches the intersection, owing to difficulties in judging the approach speed of motorcycles [10, 21]. These driver errors are more likely to occur when the rider is speeding [22, 23]. Therefore reducing the approach speed of powered two wheelers has been suggested as a promising countermeasure against collisions at intersections [23, 24]. Furthermore, lower speed provides the rider with more time to react to hazards. Hazard monitoring is a primary riding task [25], requiring the rider's awareness of the road situation and an appropriate adaptation of the riding behaviour [26]. At higher speed this task is more difficult and, thus, the crash risk increases [27–29]. The European 'Motorcycle Accidents In Depth Study' found that in almost 30% of all multi-vehicle crashes, the motorcycle rider lacked time to complete the crash avoidance manoeuvre [11]. Regardless of whether the responsibility for the intersection crashes lies with the rider or another motorist, the high vulnerability of the riders lends utmost importance to the prevention of such crashes. To drivers of other vehicles, colliding with a powered two-wheeler does not represent a comparable threat in terms of injury risk [30]. As a result, the riders need both to avoid committing errors and to be able to react safely to potential failures of other road users. Finally, approaching an intersection at lower speed allows mitigating the consequences of a possible crash, since the impact speed is related to the severity of injuries [31].

In response to the relevance of intersection crashes involving powered two wheelers and the expected safety benefits by reducing the approach speed, an intelligent intersection support system has been developed. Whenever the rider approaches an intersection at an inappropriately high speed and the system has detected a potential hazard ahead, a warning is issued. After the technical and functional aspects of the system have been presented by Biral *et al.* [32], this paper reports the results of a pilot evaluation of the intersection support in a simulator study, adopting a human factors view. This perspective comprises the riding behaviour when using the system, the riders' opinion of the ride with the system and the system design, and their acceptance of the system.

2 Intersection support system

The intersection support system has been designed with the aim of drawing the rider's attention to potential dangers that may occur at intersections owing to obstacles (mainly cars and trucks) that may unexpectedly cross the motorcycle trajectory or cut into the vehicle's lane. At a first stage, the intersection support maps the target scenario, that is it combines information coming from a laser scanner, an inertial measurement unit with GPS and a digital maps database to recognise and classify intersection situations within a set of pre-defined ones. The second stage assesses the risk level of the selected target scenario, by using non-linear optimal control, which accounts for the motorcycle dynamics and situation parameters. Depending on the identified scenario, the system calculates a safe approach manoeuvre and compares it with the rider's current speed profile to rate the intersection risk, taking into account both scenario characteristics and the rider's awareness of the situation [32].

The third, final stage is to provide a warning to the rider by a proper human machine interface (HMI). Two different interfaces have been developed, which can be alternatively installed (Fig. 1). In the first HMI, a force feedback throttle transmits the alert. If the rider is riding too fast, the stiffness of the throttle increases, suggesting the rider to decelerate. Since the warning is directly applied on a vehicle control element, possible disturbances in the riding behaviour and the riders' acceptance of the interface have to be studied carefully. The second HMI is a haptic glove, which applies a vibration to the rider's wrist. While the left glove is a traditional motorcycle glove, the right one is equipped with electronics and vibration motors. This warning type does not interfere with the vehicle controls and has no direct relation to speed or acceleration.

The target scenarios have been derived from the most relevant crash scenarios at intersections and consider two types of traffic situations. In the first one, the motorcycle has the right of way and the system detects another vehicle at the intersection, which could cut into the rider's trajectory (Fig. 2*a*). Considering the vulnerability of the rider, the system does not rely on the other road users' correct behaviour but assumes that the rider should be able to safely react to a right-of-way violation. If the motorcycle's riding behaviour differs from the corresponding reference manoeuvre calculated by the system, the rider is warned. In the second scenario type, the motorcycle has to stop or give way at the intersection (Fig. 2*b*). If the system detects that the rider does not consider the stop or give-way sign and approaches the intersection at a speed that does not permit a safe behaviour in the give-way situation, a warning is given.

3 Method

3.1 Participants

A total of 20 riders took part in the experiment (19 males and 1 female). They participated on a completely voluntary basis and were not compensated. The participants' age

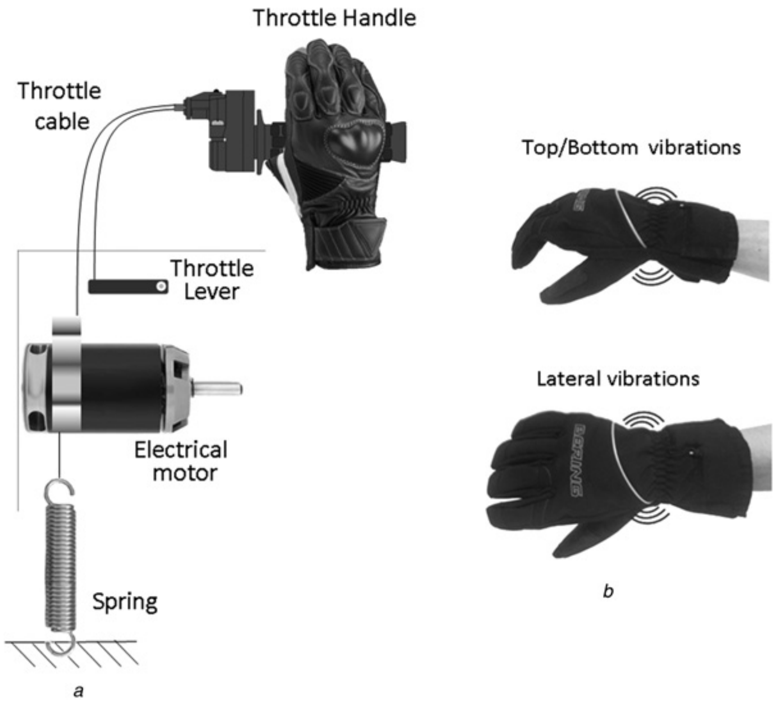

Fig. 1 *Rider interfaces*

a Force feedback throttle
b Haptic glove

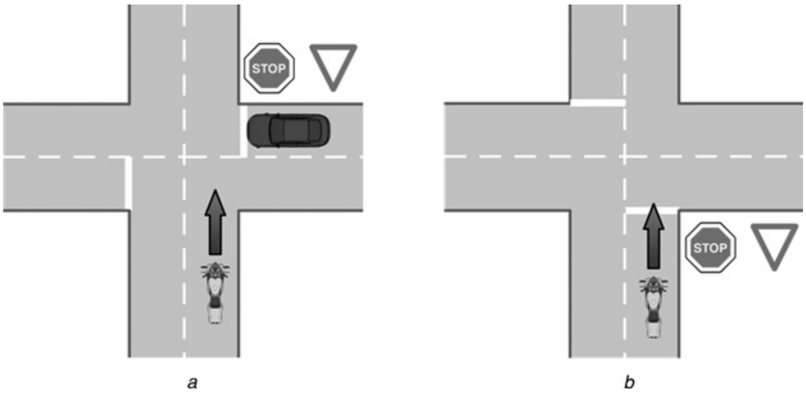

Fig. 2 *Target scenarios*
a Right-of-way situation
b Give-way situation

ranged from 22 to 36 (mean $M = 27$, standard deviation $SD = 4.1$). The majority of the riders ($n = 16$) were frequent riders who used the motorcycle at least several days a week, three riders indicated to ride only on weekends and only one rider rode less than once a week. The principal riding motive was 'fun' in $n = 16$ cases and 'commuting or mobility needs' for four of the participants. The bike used varied among the participants, with 20% scooter riders and the remaining 80% riding different types of large motorcycles.

3.2 UNIPD riding simulator

A simulator experiment has been designed in order to test the intersection support system. In this way, the hazardous intersection situations could be artificially created and controlled for (e.g. [33]), and neither the rider nor other road users were put at risk (e.g. [34]). For this purpose, the intersection support was implemented in the motorcycle riding simulator (Fig. 3) at the University of Padova (UNIPD).

The simulator is composed of an instrumented motorcycle mock-up, software for the simulation of the motorcycle dynamics and three subsystems for the motion, visual and acoustic cues. All these components have been integrated into a virtual environment where the rider may interact with other (virtual) road users and react to pre-defined events. More in detail, the motorcycle mock-up is equipped with a functionally working throttle, brake lever, pedal and gearshift, which are all sensorised and transfer the rider's action to the software that simulates the physical behaviour of the motorcycle accordingly. This application is a multibody software that works in real time and creates realistic riding conditions. As experimentally confirmed, it is able to reproduce the counter-steering behaviour as a response to the rider steering action, it simulates the effect of the rider leaning, the suspensions and reproduces tyre characteristics in detail [35, 36]. Once the behaviour of the motorcycle has been simulated, motion, visual and acoustic cues are delivered to the rider. The motion cue system of the UNIPD motorcycle simulator has five actuated axes: lateral displacement (± 0.3 m), yaw rotation ($\pm 20^\circ$), roll rotation ($\pm 20^\circ$), pitch rotation ($\pm 10^\circ$) and handlebar rotation ($\pm 10^\circ$ with a steering torque up to 100 N m). The visual cue system includes three wide screens of 2 m × 1.5 m which corresponds to a horizontal field of view of about 240° and a vertical one of 60°. Finally, a 5.1 surround system generates the environment sounds around the rider [35, 36].

Fig. 3 *UNIPD motorcycle simulator*

3.3 Simulated riding scenarios

The simulated test track had a length of about 10 km, consisting of 6.5 km on a rural road and 3.5 km in an urban scenario. A total of 26 intersections were included in the test route, which covered the traffic situations described in Section 2. Specifically, 20 right-of-way and 6 give-way intersections were present in the test route. Four of the give-way intersections were roundabouts. The traffic volume was kept low and vehicles, which could conflict with the motorcycle, were present at each intersection.

The intersection situations on the virtual test track only triggered a warning if the rider's approach speed was considered unsafe by the intersection support. Although all the participants experienced the same set of pre-defined situations, their criticality varied according to each rider's speed choice, resulting in an individual number of warnings received.

3.4 Study design and procedure

The two versions of the intersection support system were tested in a within-subjects experimental design with one factor (riding condition) at three levels. The following conditions were experienced by each participant: riding without support (baseline), riding with the intersection support using the force feedback throttle and riding with the intersection support transmitting the warning by the haptic glove. For best comparability among the conditions, the same predefined test route was used for the three rides. Equipment and instrumentation were kept constant in order to avoid change-related response biases. The alternative HMIs were activated in the corresponding experimental condition.

First, the riders were informed about the study and were given the opportunity to familiarise with the riding simulator. Then they carried out the three test rides, whose order was counterbalanced among the participants. The participants were asked to ride as they usually do, and they were reminded to obey the traffic laws. Each test ride lasted around 30 min. Before starting to ride with a system version, the participants received a practical demonstration of the warning signal. Electronic questionnaires for the subjective evaluation of the ride and the system were administered after each test ride. At the end of the experiment, a structured interview was conducted. The whole testing session took approximately 2 h and 30 min.

3.5 *Measurements and analysis*

For each experimental condition event data sets were extracted from the riding data recorded by the simulator, including 3 s approach to each intersection. Valid riding data sets were available from $N = 16$ riders; the remaining four data sets were excluded from the analysis since they were corrupted owing to a technical synchronisation problem. In order to compare the occurrence of warning events with baseline riding, critical situations that would have triggered a warning were identified in the baseline data sets. A comparison of the number of critical situations among the three experimental levels was made by means of a Friedman test, accounting for the fact that frequency counts might be skewed. The same way, the number of critical situations has been checked for order effects. The riding behaviour during the intersection approach was characterised by the mean approach speed. This riding behaviour in critical intersection situations, where the rider received a warning by the force feedback throttle or the haptic glove, was compared with those situations that remained unwarned during baseline riding. For that purpose, the intersection with the major number of riders experiencing a critical situation in all three conditions was selected, and a one-factor analysis of variance (ANOVA) for repeated measures was calculated in order to detect differences in the mean approach speed (paired samples t-tests for *post-hoc* comparisons). Again, possible order effects in the approach speed, which may result from the repetition of the test route, were examined.

The applied questionnaires included five-point Likert scales with verbal anchors ('not at all' – 'a lot') registering the riding experience (quality of riding performance, safety feeling) and judgements on the system (influence on riding, helpfulness to manage the critical event, appreciation, estimation of appreciation by fellow riders). Differences between the three rides have been detected by means of Friedman tests (*post-hoc* comparisons: Wilcoxon signed rank tests) and the two system versions have been compared using Wilcoxon signed rank tests.

The degree of the riders' willingness to have the system installed on their bike was registered on a five-point verbal answering scale. The participants indicated their willingness to pay for the system by choosing one of five given price intervals, from '€0 (only stock)' to ' >€1000'. They were furthermore given three answering alternatives to describe their intention to use the system (if it was installed on their bike): 'keep active all the time', 'activate only in certain situations' or 'not activate at all'.

Finally, a qualitative analysis of the riders' comments gives insights into possible disturbances the participants attribute to the system and the HMI, aspects they appreciate and dislike, as well as improvement suggestions they have.

4 Results

During the baseline ride, the participants went through an average of 12.2 (SD = 3.37) critical intersection situations that would have triggered a warning. They received $M = 11.7$ warnings (SD = 3.91) when riding with the force feedback throttle and $M = 11.1$ alerts (SD = 4.01) when using the haptic glove. No significant differences in the number of critical situations could be detected among the three conditions. This finding indicates that the use of the system did not provoke a general change in the riding behaviour, which would have prevented the occurrence of potentially critical intersection approaches. Likewise, tests for order effects revealed that the number of critical situations did not differ significantly from the first to the third ride. Habituation effects owing to the repetition of the test route can hence be ruled out.

The number of critical situations per intersection is displayed in Fig. 4, comparing the baseline ride (warnings are not delivered to the rider), the ride with the force feedback throttle and the one with the haptic glove. At several intersections none of the riders received a warning. The scenarios 10, 23, 25 and 26 are roundabouts and intersections 14 and 24 are give-way intersections. The absence of critical situations in all give-way scenarios across the three riding conditions suggests that the riders already adapt their behaviour sufficiently to the setting and do not need to be warned. All the riders reduced the speed within comfort deceleration limits and engaged the intersections at a low speed, compatible with the presence of other road users.

In contrast, the non-appearance of critical situations at intersections 4 and 15 can be attributed to the characteristics of the virtual test track. Intersection 4 is located 84 m after a 90° curve and therefore the riders' speed at the intersection is still low. Intersection 15 appears within 100 m after to the give-way scenario, preventing the riders from reaching high velocities.

Characterising the riding behaviour in critical situations, Fig. 5 shows the mean approach speed per intersection for the three rides. The scenarios where too few riders went through a critical situation across the three riding conditions were excluded. Fig. 5 indicates a clear speed reduction with both intersection support versions in the first three intersections, which are on rural roads. The following intersections are located in an urban area. There, speed is generally lower in the baseline condition and no effects of the warnings by the intersection support are distinctly visible on average speeds. In contrast, intersection 18 is approached at higher speed as a result of its wide road design. Here again, a reduction of the approach speed in response to the warnings by the intersection support can be presumed. At lower speeds, the riders' subjective risk thresholds might have been higher than the ones used by the system, prompting them to ignore the warning. However, the amount of available data does not give enough evidence in order to draw reliable conclusions.

The statistical analysis of the riding behaviour during the approach to the exemplary intersection revealed a marginal effect of the riding condition [ANOVA: $F(2, 24) = 2.61$, $p = 0.094$, $\eta^2 = 0.18$]. *Post-hoc* comparisons evidenced a

doi: 10.1049/iet-its.2011.0130

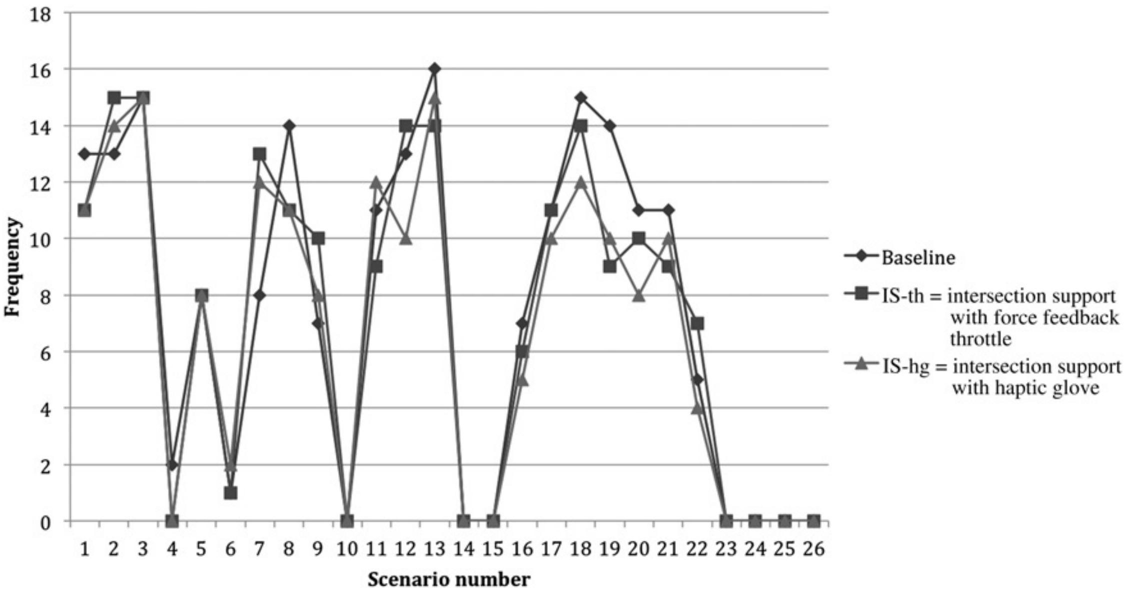

Fig. 4 *Number of critical situations per intersection for the three conditions*

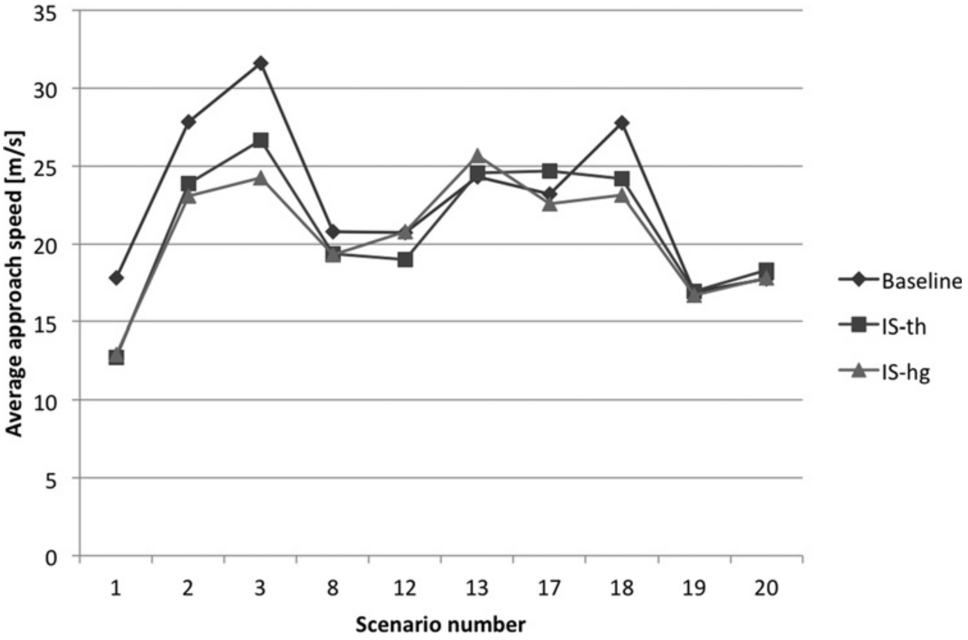

Fig. 5 *Average approach speed to the intersection in the three conditions*

significant decrease of the mean speed ($p = 0.05$) after a warning of the haptic glove ($M = 24.6$ m/s, SD = 9.94 m/s) compared to the baseline ($M = 31.4$ m/s, SD = 8.14 m/s) and a reduced approach speed ($p = 0.10$) when warned by the force feedback throttle as a tendency ($M = 26.8$ m/s, SD = 8.89 m/s). No systematic differences in the approach speed have been found between the two system versions. Results of the test for order effects in the approach speed to the exemplary intersection were not significant. Thus, the behaviour in later rides was not influenced by the experience in earlier rides.

Yet, the analyses of the questionnaire data show that the riders perceived a stronger influence on their riding by the haptic glove than by the force feedback throttle (Wilcoxon signed rank test: $Z = 2.56$, $p = 0.011$, $r = 0.57$, Fig. 6) and attributed a higher helpfulness in managing critical events to the haptic glove than to the force feedback throttle (Wilcoxon signed rank test: $Z = 2.82$, $p = 0.005$, $r = 0.63$). Accordingly, the participants rated their riding performance significantly better when they were using the intersection support with the haptic glove than when they were using the system with the force feedback throttle, with the baseline measurement falling in between [Friedman test: $\chi^2(2) = 5.50$, $p = 0.064$; *post-hoc* comparisons: B/throttle: n.s., B/glove: n.s., throttle/glove: $Z = 2.44$, $p = 0.015$, $r = 0.55$]. Moreover, the participants deemed the safety of the ride higher when they used the intersection support with the haptic glove than when they rode with the system with the force feedback throttle [Friedman test: $\chi^2(2) = 5.20$, $p = 0.074$; *post-hoc* comparisons: B/throttle: n.s., B/glove: n.s., throttle/glove: $Z = 2.29$, $p = 0.022$, $r = 0.51$].

Likewise, the riders significantly appreciate the haptic glove more than the force feedback throttle (Wilcoxon signed rank test: $Z = 2.37$, $p = 0.018$, $r = 0.53$). Regarding

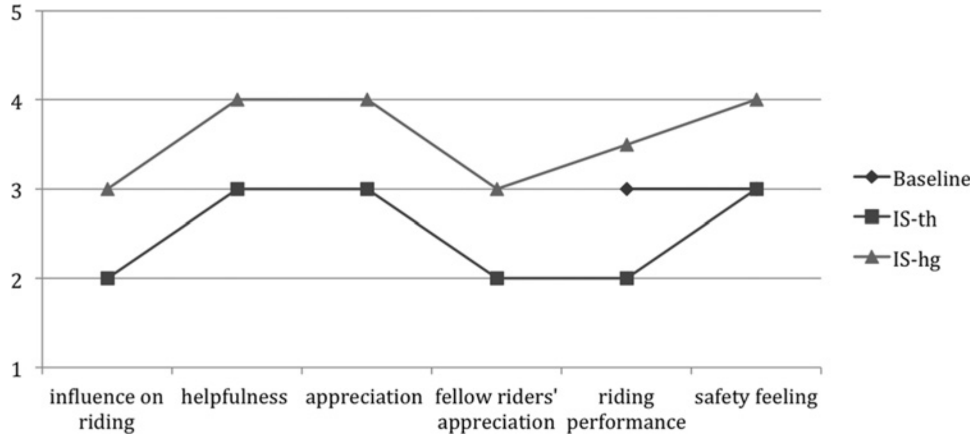

Fig. 6 *Median values for subjective ratings of the system (IS-th and IS-hg) and the ride (Baseline, IS-th, IS-hg)*

the question as to whether their fellow riders would appreciate the system, the riders' opinions show a marginally significant difference in favour of the system with the haptic glove (Wilcoxon signed rank test: $Z = 1.96$, $p = 0.051$, $r = 0.44$).

Less than half of the riders ($n = 9$) indicated that they would like to have the intersection support with the force feedback throttle installed on their bike, whereas this figure increases to $n = 14$ for the system with the haptic glove. Yet, the distribution of the degree of the willingness to have the system reveals a rather hesitant acceptance for both rider interfaces (Fig. 7).

The participants showed a relatively low willingness to pay for the acquisition of the intersection support, regardless of the implemented HMI. The distribution of chosen price intervals was identical for both system versions. The options '€0 (only stock)' and '<€100' were chosen by five riders each, nine participants stated to be willing to pay €100–250 and one test rider chose the interval of €250–500. No test rider would pay more than €500 for the system.

Most of the riders would activate both system versions only in certain situations (throttle: $n = 10$, glove: $n = 12$). Although $n = 6$ riders do not show any usage intention of the force feedback throttle, only $n = 3$ riders indicate that they would not activate the haptic glove at all. The intention to keep the system active all the time is expressed by $n = 4$ riders for the intersection support with the force feedback throttle and $n = 5$ riders for the system with the haptic glove.

When given the opportunity to comment on the system, the riders criticised the force feedback throttle owing to its invasiveness. Although they recognise the relatively low intensity of the warning signal, the riders are afraid the interventions of the force feedback throttle could distract from riding and have a negative impact on riding comfort and riding pleasure. The influence of the force feedback on the handling of the throttle was commented to be particularly problematic when the rider's intention (e.g. to quickly pass the intersection) conflicts with the system behaviour.

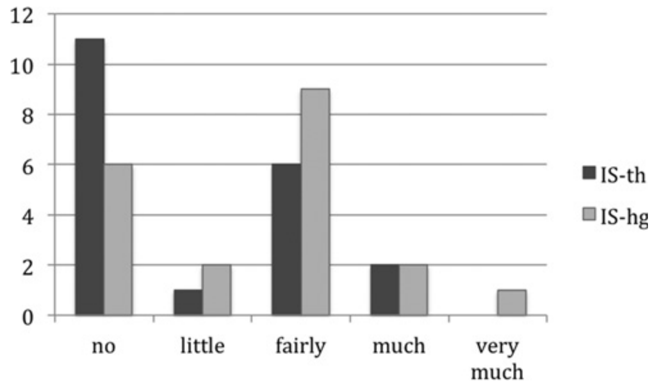

Fig. 7 *'Would you like to have this system on your bike?' – distribution for the IS-th and the IS-hg*

The haptic glove, in turn, is appreciated for its non-invasiveness. However, the riders pointed out that the glove vibrations are sometimes too strong or insisting and could therefore also distract from riding. Consequently, it was suggested to adjust the tuning of the vibrations better and to improve the ergonomic design of the glove. For both the force feedback throttle and the haptic glove, some riders wish they had the possibility to manually customise the signal intensity and warning threshold, and they furthermore underline the importance of a manual switch-off key. Scooter riders raised a potential shortcoming of the haptic glove in comparison to the force feedback throttle, pointing out that they do not always wear gloves.

The riders' comments revealed their approval of the intersection warning function itself and their consideration of the warning by the haptic glove as appropriate to the situation. The usefulness of the intersection support was deemed particularly high in unknown environments and with low visibility. Some riders estimated that the safety potential of the system could increase, once they would gain more confidence in its use.

5 Conclusion and discussion

The evaluation of the intelligent intersection support from a human factors perspective gives valuable insights regarding the riders' subjective assessment of the two tested system versions and provides first results on the objective effects of the system on the riding behaviour at intersections. Neither the intersection support with the force feedback throttle nor the system with the haptic glove leads to a generally more cautious behaviour compared to riding without assistance. Ideally, the intersection support would help the riders reset the threshold of their own judgement of a safe approach speed, thus reducing the number of warnings needed. Although the present study does not find such an influence on the riding behaviour, these effects are not necessarily ruled out. They should be investigated after a long-term use of the system, since the riders might need more experience with the system to internalise the safety threshold suggested by the intersection support.

doi: 10.1049/iet-its.2011.0130

On the other hand, the study shows that once a warning is issued the approach speed to the intersections is significantly lower than when the situation occurs without a warning, especially when the haptic glove transmits the alert. However, it has to be considered as a limitation that statistical testing was restricted to one intersection, since not enough critical situations could be collected throughout the conditions at other intersections owing to the riders' appropriate approach behaviour. Thus, the reported findings on the riders' reactions are restricted to an exemplary junction, representing a very specific though relevant sample. Further studies need to be undertaken so as to obtain results that are generalisable to other intersections. The descriptive analyses of the mean approach speed to the intersections point towards an effectiveness of the system only at high-speed locations (especially rural environments). Additional studies should provide more solid evidence on the effects of the system use in environments with lower speed, considering the potential necessity to adjust the warning thresholds.

The fact that warnings were only issued at right-of-way situations suggests that the riders do not need the intersection support in give-way scenarios. Before modifying the system functionality, further studies should be undertaken to confirm this result.

The subjective findings reveal a clear preference of the system version with the haptic glove. This includes significantly better judgements on the helpfulness of the warnings and the resulting quality of the riding experience. Furthermore, the riders in this study explicitly point out the annoyance provoked by the intrusiveness of the force feedback throttle. Similarly, previous findings on a curve warning system [37] and intelligent speed adaptation [38] for riders have shown low acceptance of a force feedback throttle. Although this HMI is fairly effective in provoking the desired behavioural reactions, its rejection by the riders hinders it from being recommendable. The riders' concerns of possible distraction and interference with riding operations reinforce that the implementation of a force feedback throttle to transmit a warning should be avoided.

Hence, the objective effectiveness of the system does not seem to depend on the HMI employed, whereas the subjective evaluation of the interface shows to be decisive for the acceptance of the support function by the riders. Still, the results on the willingness to have the system installed on the own vehicle underline the need to further improve the system and its HMI, even the haptic glove. Next development steps should also account for the differences between specific user groups, for example the needs of scooter riders.

For both system versions, the riders show a usage intention that is restricted to certain conditions. As a consequence, such a flexible use should be made possible by a switch off button which is easy to use, and options for personal customisation of the warning parameters could be offered in order to enhance the riders' acceptance. The adaptability of the system adjustments could help increase the frequency and duration of the system use, incrementing thereby its possible impact on the riding safety. Further studies are needed to investigate the usage behaviour in detail.

Given that the low willingness to pay for the system proved to be independent from the HMI, improving the design of the system might not easily influence the riders' acceptance in terms of economic value. This issue therefore has to be dealt with in the further technical development, offering affordable solutions of the intersection support. Without acquiring the system, the rider will not get the chance to use it and to benefit from its safety potential.

According to the findings of this study, the intersection support can be valuable as a safety measure, which is complementary to the improvement of rider conspicuity. As stated by Pai [30], past research efforts on the effectiveness of conspicuity aids have not been sufficiently conclusive. The intersection support tackles the safety issue of intersection crashes from an alternative point of view, without relying on the correct behaviour of the other road users.

Still, the present study was limited to a simulated environment and a relatively small sample of riders. More extensive experiments should be undertaken, employing larger participant samples and including field studies. In that way, the benefits of the system under more realistic riding conditions should be analysed, considering aspects of the rider state such as distraction.

In order to explore the effects of the long-term use of the system, future research should take into account how the usage behaviour evolves over time and aim at predicting possible behavioural adaptation. Special attention should be given to risk compensation and habituation effects that might occur when the riders get used to the support function. There might be a danger of the riders developing overconfidence in the assistance system, leading them to lower their own level of vigilance of other traffic and to assume that the system takes over this part of the riding task and protects them by giving speed advice whenever necessary. Such declining efforts in hazard monitoring would carry particular danger in case of system failures. Extensive studies are needed to make sure that changing rider behaviour does not offset the safety potential of the intersection support that the results of the present investigation point towards.

6 Acknowledgments

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n°216355. It was carried out while the first author was a member of the Accident Analysis and Human Factors Department at the CIDAUT Foundation (Parque Tecnológico de Boecillo, P.209, 47151 Boecillo, Spain). The authors would like to thank the members of the SAFERIDER project consortium who have contributed to this study.

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