Intelligent speed adaptation as an assistive device for drivers with acquired brain injury: A single-case field experiment

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\textbf{Abstract}

Intelligent speed adaptation (ISA) was tested as an assistive device for drivers with an acquired brain injury (ABI). The study was part of the “Pay as You Speed” project (PAYS) and used the same equipment and technology as the main study (Lahrmann et al., in press-a, in press-b). Two drivers with ABI were recruited as subjects and had ISA equipment installed in their private vehicle. Their speed was logged with ISA equipment for a total of 30 weeks of which 12 weeks were with an active ISA user interface (6 weeks = Baseline 1; 12 weeks = ISA period; 12 weeks = Baseline 2). The subjects participated in two semi-structured interviews concerning their strategies for driving with ABI and for driving with ISA. Furthermore, they gave consent to have data from their clinical journals and be a part of the study. The two subjects did not report any instances of being distracted or confused by ISA, and in general they described driving with ISA as relaxed. ISA reduced the percentage of the total distance that was driven with a speed above the speed limit (PDA), but the subjects relapsed to their previous PDA level in Baseline 2. This suggests that ISA is more suited as a permanent assistive device (i.e. cognitive prosthesis) than as a temporary training device. As ABI is associated with a multitude of cognitive deficits, we developed a conceptual framework, which focused on the cognitive parameters that have been shown to relate to speeding behaviour, namely “intention to speed” and “inattention to speeding”. The subjects’ combined status on the two independent parameters made up their “speeding profile”. A comparison of the speeding profiles and the speed logs indicated that ISA in the present study was more efficient in reducing inattention to speeding than affecting intention to speed. This finding suggests that ISA might be more suited for some neuropsychological profiles than for others, and that customisation of ISA for different neuropsychological profiles may be required. However, further studies with more subjects are needed in order to be conclusive on these issues.

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1. Introduction

Intelligent speed adaptation (ISA) has been studied extensively in the past two decades. The first line of research within the field tended to focus on technologies that aimed to reduce the subjects’ mean speed when driving with active ISA, and most of these technologies were successful in doing this (reviews: Regan et al., 2006; Warner, 2006). A second line of research within the ISA field is now appearing, dealing with the more user-centred issues. ISA problems relating to the user, e.g. poor acceptance of ISA equipment and difficulties in recruiting subjects for ISA-studies, have proven difficult to be solved. From this, it has been concluded that the drivers who need ISA the most may not be willing to use it voluntarily (Lahrmann et al., in press-a, in press-b; Jamson, 2006).

The idea to test ISA with drivers having acquired brain injury (ABI), which is a narrower inclusion criterion than seen in other studies, arose in the wake of the above conclusion. Given that ISA has a potential for reducing (a) the cognitive workload of driving by demanding less attention for monitoring speedometer and speed limit signs, and (b) decision making processes associated with choosing an appropriate speed (if the driver complies with the system), then drivers with ABI compose a group of users who might not only need the equipment, but also might voluntarily want it as an assistive device that facilitates post-injury driving. The prevalence of persons with ABI is growing due to medical advances leading to improved survival rates. Since the ability to drive after an ABI has been associated with high measures of autonomy and quality of daily life (Fisk et al., 1998; Edwards et al., 2006), it seems a new and promising field of implementation to use ISA as an assistive device. However, the inherent problem of most assistive devices is
Table 1
Dichotomized terms parallel to “intention to speed” and “inattention to speeding”.

<table>
<thead>
<tr>
<th>Intention to speed</th>
<th>Inattention to speeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Violation</td>
<td>Error</td>
</tr>
<tr>
<td>Poor selection of target speed</td>
<td>Poor adjustment of speed to target speed</td>
</tr>
<tr>
<td>Social context contributors to speeding</td>
<td>Information processing problems</td>
</tr>
<tr>
<td>Attitude and motivation problems</td>
<td>Unconscious speeding</td>
</tr>
<tr>
<td>Conscious speeding</td>
<td>Involuntary speeding</td>
</tr>
<tr>
<td>Deliberate speeding</td>
<td></td>
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</tbody>
</table>

whether it is independent of the processes that it is supposed to compensate for. If one makes an assistive device to support memory function, it is important that the use of the device is intuitive and does not itself require memory. In the same way it is important that the ISA equipment does not attract more attention than is freed by its functionality. Clarifying whether ISA in some situations becomes a distraction will be our first focus in the present study.

Our second focus describes the subjects’ speeding profile and its interaction with ISA. As ABI is associated with a multitude of cognitive deficits, we preferred to have a conceptual framework as a basis for the speeding profiles, which only focused on the cognitive areas shown to be related to speeding behaviour. Literature in the field displayed a tendency to divide the causes of speeding into two main categories, which we in this cognitive-oriented context will term “intention to speed” and “inattention to speeding”. Some of the related terms are listed in Table 1 (Reason et al., 1990; Aberg and Warner, 2008).

The categories are often presented as dichotomised, i.e. mutually exclusive (e.g. as in the title “Speeding – deliberate violation or involuntary mistake?” (Aberg and Warner, 2008)). In our work we will use the idea of these two categories as being the main contributors to speeding behaviour, but rather than regarding “intention to speed” and “inattention to speeding” as dichotomised categories, we consider them to be independent parameters, i.e. the presence of one of the two does neither exclude nor include the presence of the other. If tools were constructed specifically for measuring “intention to speed” and “inattention to speeding”, it would be possible to display a driver’s “personal speeding profile” as a point in a coordinate system with the parameters represented on the x- and y-axis, respectively. A simplified version of such a coordinate system is the cross-tab presented in Table 2. The four speeding profiles in Table 2 correspond to the four extreme corners of the coordinate system.

One of the advantages of the independent parameters approach is that all causes of speeding can be addressed in cases with more than one contributing parameter (speeding profiles which approach profile 4 in Table 2). Seeing the two as independent becomes especially meaningful when working with drivers with ABI; although both “intention to speed” and “inattention to speeding” are normal findings in all populations, the parameters can also be sequelae of ABI (reduced executive functions/reduced attention). Lesion studies have found double dissociations between these cognitive areas, implying that it is possible to have reductions in either of the two cognitive areas independently, or in both, depending on the location of the injury.

Table 2
Cross-tab of the independent parameters “intention to speed” and “inattention to speeding”, producing four speeding profiles.

<table>
<thead>
<tr>
<th>Intention to speed</th>
<th>Inattention to speeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profile 1: No speeding</td>
<td>Profile 2: Sporadic speeding</td>
</tr>
<tr>
<td>Driver has no intention to speed</td>
<td>Driver has no intention to speed</td>
</tr>
<tr>
<td>and driver attends to speeding</td>
<td>but driver is inattentive to</td>
</tr>
<tr>
<td></td>
<td>speeding</td>
</tr>
<tr>
<td>Profile 3: Controlled speeding</td>
<td>Profile 4: Unrestrained speeding</td>
</tr>
<tr>
<td>Driver has an intention to speed</td>
<td></td>
</tr>
<tr>
<td>and driver attends to speeding</td>
<td>Driver has an intention to speed</td>
</tr>
<tr>
<td></td>
<td>and driver is inattentive to</td>
</tr>
<tr>
<td></td>
<td>speeding</td>
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</table>

The present study, which is a sub-study to the project “Pay as You Speed” (PAYS) in North Jutland (Lahrman et al., in press-a, in press-b), did not have the possibility to recruit subjects by screening medical journals, therefore, recruitment took place in cooperation with a local brain injury rehabilitation centre, which resulted in recruitment of only two subjects. Obviously, with only two subjects it is not possible to perform a complete test of the framework described above; however, we decided to go forward with a small study using a mix of quantitative data (single case ABA research design) and qualitative data (semi-structured interview) to explore whether ISA holds enough potential as an assistive device to justify further research.

2. Material and methods

2.1. Equipment

The equipment consisted of an onboard unit (OBU) that used the GPS position of the vehicle to match its speed to the speed limit (retrieved from a digital map). A display mounted on the dashboard showed the current speed limit. If this speed limit was exceeded with more than 5 km/h the following voice message was given: “50 (the actual speed limit)—you are driving too fast”. This message was repeated every sixth second until the speed was below the activation criterion (speed limit +5 km/h). The equipment was essentially the same as that used in PAYS (Lahrmann et al., in press-a, in press-b), except that the display only showed the speed limit and no additional information.

2.2. Recruitment of subjects

Subjects were recruited with support from the local centre for brain injury rehabilitation in Aalborg (“Hjerneskadecentret”). The centre sent out letters to clients who had received rehabilitation at the centre within the previous four years and had retained their driver’s license after acquiring a brain injury. A total of 15 persons met these inclusion criteria. Two persons responded and accepted to volunteer as subjects in the study.

2.3. Procedure

2.3.1. ISA driving data

The field experiment was conducted as a single case ABA design. The two subjects had ISA equipment installed in their private vehicle for 30 weeks. The first six weeks served as a Baseline period (A—Baseline 1) during which the speed was recorded, but the user
interface of the ISA system was inactive, i.e. both the display and the voice message were switched off. During the subsequent 12 weeks (B—ISA period) ISA was fully active with the speed limit shown on the display and the voice message played if the subject exceeded the speed limit. Finally, the user interface of ISA was again inactive (A—Baseline 2) while the speed of the vehicle was recorded for another 12 weeks (Fig. 1).

2.3.2. Semi-structured interviews

The two subjects were interviewed on two occasions. The first interview took place at the time of ISA instalment (beginning of Baseline 1). This interview was concerned with how the subjects handled the task of driving with an ABI. The second interview took place just after the subjects had finished driving with the active ISA user interface (beginning of Baseline 2). The foci of this interview were the subjects’ experience of driving with ISA, in particular their possible experience of distraction from the equipment, and on the possible shift in their driving strategy caused by ISA (Fig. 1).

3. Results

3.1. GJ

3.1.1. Neuropsychological profile

At the time of the experiment (spring, 2007) GJ was a 67-year-old woman. Her brain injury was caused by meningitis in 1988. At the time of injury she worked as head of the administration in a fairly large organization, but the brain injury led to early retirement. Upon admission to the centre for brain injury rehabilitation in 2002, she underwent neuropsychological testing. All her test scores were found to be within the normal range of cognitive functioning (scores corrected for age and education). However, the neuropsychologists at the centre assessed that GJ most likely had a very high level of pre-morbid functioning and that the injury had reduced her ability to concentrate (attention problems), corresponding to GJ’s subjective experience of having problems doing more than one thing at a time. Still, GJ’s cognitive problems should be considered to be very mild.

3.1.2. Interviews

In the first interview with GJ, it became clear that driving had become more challenging on a cognitive level after acquiring a brain injury. She reported how driving took up so much of her cognitive capacity that she often lacked capacity for focusing on what direction she should be going. Keeping track of the speed limits during driving also used a considerable amount of her cognitive capacity. When asked about her ability to detect speed signs, she replied that she was quite confident that she saw all speed signs, but that this implied reduced attention to other parts of the traffic scene. GJ described how she, after acquiring her brain injury, had decided to comply with the speed limits, but was aware that she was not always successful in doing so. She experienced that she ended up going too fast when she focused on other aspects of driving, e.g. she described how she was often surprised when looking down on the speedometer after focusing on the traffic scene and finding that she was going 10 km/h faster than the speed limit. She explained that her problems were not caused by not concentrating enough, but rather by not being able to do more than one thing at a time.

In the second interview, GJ stated that she had never experienced confusion or distraction as a result of the ISA equipment. She found that the greatest advantage of driving with ISA was that she did not have to change gaze direction as often as when driving without ISA. She explained how she felt that she was able to get a better outlook when driving with ISA. Furthermore, she explained how she experienced driving with ISA as a more relaxed way of driving because she could pay attention to the driving task without having to monitor the speedometer. Her strategy for choosing driving speed with ISA was simply to drive on her intuition until the ISA voice message played, after which she adjusted her speed.

3.1.3. Speed log

Out of the total distance driven within a given period, a percentage is driven with a speed that exceeds the speed limit with a minimum of 5 km/h (ISA activation level). We termed this measure “percentage driven above” (PDA). GJ’s PDA was 8.7% in Baseline 1, but it decreased to 2.4% in the ISA period. After the termination of the ISA experiment, Baseline 2 showed a PDA of 17.4%. Fig. 2 presents these data along with a PDA value for each of the 30 weeks of the experiment.

These data were submitted to a total of five significance tests, and alpha was set at 0.01 (Bonferroni corrected). Since the study is a single case design, we primarily chose to apply non-parametric ranking tests. The weekly PDA values were submitted to a Kruskal–Wallis test, which found the difference between the three periods to be statistically significant ($\chi^2(2, N=30) = 19.0$, $p < 0.001$). Subsequently, Mann–Whitney U tests were used for pair-wise comparison of the three periods. The PDAs of the ISA period was lower (statistically significant) than the PDAs of both Baseline 1 ($U(N=18) = 5$, $p = 0.002$) and Baseline 2 ($U(N=24) = 2$, $p < 0.001$), whereas the there was no statistical significant difference between Baseline 1 and Baseline 2 ($U(N=18) = 24$, $p = 0.26$). Thus, these results indicate that the statistically significant difference found in the Kruskal–Wallace test related to the difference between ISA and no ISA. Even though the variance within Baseline periods was quite large (Baseline 1: SD = 6.8, Baseline 2: SD = 11.2), a linear regression analysis which used the three experimental periods to predict PDA values explained 37.2% of the variance in data ($R^2 = 0.372$, $F(2,27) = 8.0$, $p = 002$).
3.2. KB

3.2.1. Neuropsychological profile

At the time of the experiment (spring, 2007) KB was a man aged 54. He had a stroke in 1999 and another in 2001, which resulted in early retirement from his work as a sales representative. Neuropsychological tests of KB were conducted in relation to his admission to the centre for brain injury rehabilitation in Aalborg in 2003. The tests indicated reduced attention and memory functions when presented with complex material. Both visuo-perceptual and visuo-constructive functions were reduced, and the tests results also revealed executive problems: KB had reduced problem solving skills with a tendency towards being impulsive and working uncritically without re-checking. The assessment from the neuropsychologist at the centre furthermore states that KB lacks full awareness of the cognitive implications of his brain injury.

3.2.2. Interviews

In the first interview with KB he stated that his main problems after acquiring his brain injury were a reduced short term memory and “spatial confusion”, which he felt made it difficult for him to navigate in traffic. KB explained that he did not comply with the speed limits in general, only in certain situations, e.g. when encountering road work or driving on urban roads, did he intend to stay below the speed limit.

After driving with ISA, KB found the equipment to be “a stroke of genius”. He stated that the equipment had never disturbed or confused him, though he remembered being irritated at the voice message in the beginning. However, he felt that he quickly got accustomed to it. When asked to compare driving with and without ISA, he replied that he found it more relaxing to drive with ISA because he could use more effort on driving properly. KB mentioned that a part of his driving strategy with ISA was to monitor the speedometer more closely in order to stay below the speed limit and not activate the voice message. KB did not experience it as a problem that he had to change gaze direction more often, since he considered it an effortless task. He also described that there were situations in which he felt too busy to comply with the voice message. When this happened he increased the volume on his car radio to mask the voice message.

3.2.3. Speed log

KB started out with a PDA of 42.1% in Baseline 1. In the ISA period the PDA decreased to 14.6%, but went back up to 34.0% in Baseline 2. Both PDA values for the three periods and for each week are presented in Fig. 3.

As in the case of GJ the data of KB were submitted to a total of five statistical tests, which with a Bonferroni correction set alpha 0.01. A Kruskal–Wallis test was used on the weekly PDA values, and a statistically significant difference between the three periods was found (χ²(2, N = 30) = 19.1, p < .001). Mann–Whitney U tests were used to compare the three periods pair-wise. The ISA period had a statistically significantly lower PDA than both Baseline 1 (U(N = 18) = 2, p = 0.001) and Baseline 2 (U(N = 24) = 4, p < 0.001). The difference between Baseline 1 and 2 was not statistically significant (U(N = 18) = 24, p = 0.26). A regression analysis showed that a model which used the experimental periods to predict PDA values accounts for 57.7% of the variance (R² = 0.577, F(2,27) = 18.4, p < 0.001). A specification of KB’s PDA for urban roads was added to Fig. 3 in order to be able to examine his claim of not speeding in urban areas during Baseline 1.

Both KB and GJ’s weekly PDA was reduced one to two weeks ahead of the activation of the user interface of ISA (towards the ending of Baseline 1). We have searched for possible explanations for this finding, including errors in data, but have not found any. For now we consider it to be a coincidental expression of the variation found in data from Baseline 1.

4. Discussion

There was nothing in the interviews that indicated distraction or confusion as a result of using ISA. Both the subjects reported being content with the equipment and did not recollect instances of being interrupted by the voice message. The subjects also stated that they found driving with ISA a more relaxed way of driving, which implies that the voice messages were considered as a support rather than a stress factor by both the subjects.

The assessment of the speeding profile (Table 1) of the two subjects was based on their statements from interview 1, their actual speeding behaviour (speed log—Baseline 1), and their neuropsychological data. The effect of ISA on the parameters “intention to speed” and “inattention to speeding” was also evaluated using both
interview data (interview 2) and the actual speeding behaviour (speed log—ISA period and Baseline 2).

GJ's speeding profile resembled that of profile 2 in Table 2, “sporadic speeding”. In the interviews with GJ she presented herself as having no intention to speed, but problems with inattention to speeding. This view was supported by her neuropsychological profile that indicated small functional reductions within the area of attention, but no problems forming adequate intentions (no executive problems). During Baseline 1 of the speed log, GJ had some weeks with a very low PDA and some with a higher PDA (range = 2.17–18.48), which supports the idea that speeding was not a regular part of her driving pattern, but rather something that occurred when she was inattentive to speeding.

The interaction between GJ and ISA resulted in a very positive effect on GJ’s PDA; in the ISA period the weekly PDAs approached a minimum (range = 0.90–4.12, M = 2.00, SD = 0.82). This finding fits very well with the reported strategy: because GJ did not monitor the speedometer she occasionally exceeded the speed limit (which implies that PDA must be greater than 0), but she complied with the voice message, resulting in the low PDA values observed. Although her strategy was very effective during the ISA period in both reducing PDA and improving her outlook, she rapidly returned to a higher PDA when the user interface was switched off. Baseline 2 not being lower than Baseline 1 indicates that there was no training effect of ISA. In fact, when the two Baseline periods are compared, there seems to be a trend towards higher PDAs in Baseline 2. The difference is not statistically significant, but the trend might indicate that the equipment could create dependency for its user, which is worth to bear in mind in future studies of ISA effects. In this particular case, the dependency could be a result of GJ’s user strategy, which appears to be at the border between use and misuse, i.e. it contained aspect of overreliance (Parasuraman and Riley, 1997). However, it was also this strategy that provided her with the benefits of low PDAs and improved traffic overview.

The temporary nature of the effect of ISA and GJ’s stated user strategy imply that GJ used ISA as a “cognitive prosthesis” (Cole, 1999). A prosthesis is a tool used as compensation for a lost function or limb. If a prosthesis is not available and working it is of no help to the user. In fact, once accustomed to the prosthesis, any absence of the prosthesis will possibly leave the person with greater problems than before relying on the prosthesis since no other compensatory techniques have been developed. This does not imply that we should stop making prostheses, but rather acknowledge that overreliance is an inherent aspect of the user-technology relationship.

The speeding profile of KB differed from that of GJ. In interview 1 he explained that he was an intentional speeder, but that he did not experience any problems with inattention. He also claimed that he was capable of controlling his intentional speeding, e.g. by not speeding in urban areas. However, this explanation was neither supported by the neuropsychological profile nor the speed log from Baseline 1. The neuropsychological testing of KB had shown reduced attention and memory functions when presented with complex material, which—in combination with KB’s self reported intentions—would make KB an “unrestrained speeder” (profile 4, Table 2). The speed log revealed that although KB had a lower PDA in urban areas than in other areas, his amount of speeding in urban areas was far from minimal (range = 22.60–28.45, M = 24.77, SD = 2.21), which indicated that inattention plays a far greater role in KB’s speeding violations than acknowledged by himself. The discrepancy between KB’s statements and objective findings could result from his poor understandings of the cognitive implications of his brain injury.

The interaction between KB and ISA differed in some aspects from the case of GJ. Although the active user interface had a statistically significant effect on the PDA values in the ISA period, KB’s situation was not of a minimum PDA (range = 8.15–23.14, M = 14.19, SD = 4.05). As a profile 4 driver (Table 2), ISA would have to affect both intentions to speed and inattention to speeding in order for KB to obtain a minimum PDA situation in the ISA period. Both the fact that it is difficult to imagine speeding in the ISA period as a result of inattention when voice messages are given at relevant times and the fact that KB reported intentionally masking the voice message with loud radio suggest that ISA was less successful at decreasing intention to speed than inattention to speeding. Our independent parameters view on “intention to speed” and “inattention to speeding” presented in the introduction is critical to this analysis. Had we seen KB’s speeding problem as being caused be either “intention to speed” or “inattention to speeding” (dichotomised approach), we would have had to say, that his primary problem was that of forming appropriate intentions. After observing a statistically significant reduction in the PDA’s in the ISA period, we would then have had to make the complete opposite conclusion, namely, that ISA was successful in reducing intention to speed.
In the case of GJ, ISA constituted a “cognitive prosthesis”, but the way KB used ISA, it was closer to a training device. Where ISA caused GJ to look less on the speedometer, which resulted in a better traffic overview, the presence of active ISA caused KB to monitor the speedometer more closely (when not intentionally speeding), in order to prevent the activation of the voice message. This means that KB had some training during the ISA period in being more attentive to his speed. However, ISA cannot be said to be an effective training device, since the difference between Baseline 1 and 2 was not statistically significant on the ranking tests. There was a trend towards lower PDAs in Baseline 2, but even if further research was successful in achieving statistically significant training effects in Baseline 2 after applying ISA as a training device (driving with a goal of not activating voice message), it is still a problematic way of using ISA. It is undesirable to have a person with attention problems spending a great deal of his (reduced) cognitive capacity on monitoring the speedometer since it implies looking away from the traffic scene.

5. Conclusion

Two subjects with ABI had a statistically significant reduction in their amount of speeding when driving with active ISA, which is a result comparable to studies with other user groups (Lahrmann et al., in press-a). The effect of ISA did not carry over to the period after inactivation of the ISA user interface (Baseline 2). The observed relapse to speeding suggests that ISA would be more effective if applied as a permanent cognitive prosthesis for speed monitoring rather than a temporary training device. Based on our view on “intention to speed” and “inattention to speeding” as independent parameters behind speeding behaviour, ISA was found better suited for affecting inattention than intention; however, further studies are needed in order to substantiate this interpretation of our data. As the study included only two subjects no conclusions on the general usefulness of ISA for persons with ABI can be drawn. Apart from including more subjects we propose that future studies should focus on specifying the neuropsychological profiles that would benefit most from using ISA as a cognitive prosthesis, and on the possibilities of customising ISA for different neuropsychological profiles.

References