Evaluating Safety Effects of In-Vehicle Information Systems

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In recent years, there has been a considerable increase in the research and development of modern technology in road transport. From the beginning, many people expressed their concern that this technology, known as advanced transport telematics (ATT) or intelligent transport systems (ITS), would jeopardize traffic safety (e.g., Hancock & Parasuraman, 1992; Parkes & Ross, 1991). Reasons for this concern include that drivers might be distracted at critical moments and that, in less critical situations, they devote too much attention to in-vehicle displays.

The present chapter describes a field study that addresses the development of a method for assessing safety effects of in-vehicle information systems as caused by distraction and information overload. That is, what should a safety assessment method look like, and what measures should be used? I believe that safety effects of in-vehicle information systems can be assessed only when normal drivers are observed in situations that are common to them. This implies that safety assessment should take place in a car in normal traffic. Safety assessment in driving simulators is not possible. Of course, driving in an experimental study is never completely normal; a device has to be handled which is relatively unfamiliar. Proper experimentation requires a certain degree of control by the experimenter, and various requirements must be fulfilled before safety related measures can be registered. Still, I consider the use of vehicles that are instrumented for this purpose a reasonable compromise (Verwey, Burry, & Bakker, 1995).

Given that safety assessment of in-vehicle information systems involves an instrumented vehicle, what are the indicators for safety? By now, there is a tradition of two methods for safety assessment. The first includes registration of various objective performance measures. If, relative to a control
participant pool. All participants were unfamiliar with the city where the experiment took place and had driven the experimental route only once before in an earlier experiment.

**Experimental Route.** The experimental route was in the Dutch city of Amersfoort. In calm traffic, the route took about 20 to 25 minutes to drive. Four different types of driving situations were distinguished: Turning right from a main road into a minor road while taking bicycles and mopeds between the vehicle and the curb into account; approaching a general rule intersection, which, in the Netherlands, implies that motorized vehicles coming from the right have priority; approaching a yield intersection from the minor road, implying that all traffic on the main road has right of way, motorized vehicles as well as bicycles. driving straight ahead at a major inner city artery. The experimental route contained three instances of each of these four situations, making up a total of 12 experimental situations. The order in which the experimental situations were encountered was as follows: general rule intersection, yield intersection, straight ahead, right turn, yield intersection, straight ahead, right turn, right turn, general rule intersection, general rule intersection, and yield intersection.

**RDS-TMC Tasks.** Participants carried out three types of RDS-TMC tasks. In two of these tasks, participants were asked to indicate whether there was congestion on a predefined route. In half the instances, the correct response was “yes”; in the remaining ones, it was “no.” The third task was a filter programming task.

In the first congestion presentation task, the *map condition*, a computer-generated voice told participants their would-be current location and their would-be destination. These locations consisted of cities in a range of about 60 kilometers from Amersfoort. Following this context information, a map was displayed on the color display that was built into the dashboard of the instrumented vehicle (Fig. 2.11.1). This map showed major roads and a number of cities. The map was artificial in that the city names were not at their usual positions, but were associated with alternative positions. This mapping was changed at each trial to mimic a situation in which drivers do not know the environment and must search the map for the relevant cities. Congestion was indicated by red road segments on the otherwise green road network. For example, the instruction was “You are driving from Utrecht to Apeldoorn. Is there any congestion?” (i.e., at the connecting roads). This instruction was supported by presenting both names on the left corner of the display to reduce the workload associated with keeping the current location and the destination in mind. After a 2 to 7 second pause, the map display was presented. Participants were instructed to verbally state whether or not there was congestion on the roads connecting the current location and des-

![FIG. 2.11.1. Example of a display in the map condition.](image)

- **TABLE 2.11.1** Example of a Trial in the Speech Condition

<table>
<thead>
<tr>
<th>Context information</th>
<th>Display</th>
<th>RDS-TMC speech messages</th>
</tr>
</thead>
<tbody>
<tr>
<td>“You are driving from Utrecht to Apeldoorn. Is there congested traffic?”</td>
<td>Utrecht → Apeldoorn</td>
<td>“At the A1, Amersfoort Apeldoorn, heavy and congested traffic.”</td>
</tr>
<tr>
<td>“The A2, Vianen Utrecht, is closed due to traffic works.”</td>
<td>“At the A27, Utrecht Almere, congestion near Blaricum.”</td>
<td></td>
</tr>
<tr>
<td>“At the A28, Utrecht in the direction of Amersfoort, congestion due to an accident.”</td>
<td>“At the A56, Apeldoorn Amersfoort, congestion in both directions due to traffic works.”</td>
<td></td>
</tr>
</tbody>
</table>

In the second task, the *speech condition*, the context information was followed by a digitized voice reading aloud five messages in a format similar to that of most RDS-TMC applications. Table 2.11.1 presents an example. As is the case in reality, this task assumes that the driver knows the location of the cities in the area. Because only larger cities were used and all participants were from the region, the participants in this study were expected to be able to perform this task.
The third RDS-TMC task involved programming a filter on the system. This filter programming task started with an instruction given by a digitized voice, for example, “Adjust Filter C for A26.” Then, participants searched with two (arrow) push buttons through a list of 54 alphabetically ordered road numbers presented on a display at the center part of the dashboard. Eight road numbers were visible at the same time; the cursor position was always in the center of the display and was highlighted. An example display is presented in Fig. 2.11.2. As soon as the proper road number was highlighted, one of four filter buttons at the right-hand side of the display (representing Filters A, B, C, and D) was pressed.

Each participant performed each of these three tasks twice in each of the four driving situations. Across all participants, the same type of task was performed equally often at each specific situation.

Apparatus and Data Registration

The experiment was carried out in one of the institute's instrumented cars (Verwey et al., 1995). This car, a Dodge Ram van with dual controls, contains an IBM 486 personal computer and has various possibilities for measuring driving behavior and generating stimuli.

Auditory stimuli were presented by a digitized, prerecorded male voice on a speaker behind the participant and were clearly audible under all driving conditions. Presentation of the stimuli was controlled by the onboard computer. Visual stimuli were presented on a backlit liquid crystal display (LCD) mounted on the center panel of the instrumented car next to the speedometer. The visual angle between the normal fixation point on the road ahead and the screen was about 27° horizontally and about 27° vertically. The eyescreen distance was about 90 centimeters for an average participant of about 1.80 meters in height. Text was clearly readable for all participants.

During the experiment, the participants’ answers were registered by the experimenter. Objective measures such as speed, stimuli presented, lane position, and actions of the participants in the programming task were registered at a sample rate of 10 hertz.

Procedure

Participants were first introduced to the aim of the study and then filled out a written consent form. Next, they were familiarized with the instrumented car and the RDS-TMC tasks they were to perform. It was explicitly stated that they were to drive safely and that they would earn a bonus of 50 cents for each correct answer on the RDS-TMC tasks as long as they would not drive in an unsafe manner. After the instruction, they drove with the vehicle for about half an hour without performing an additional task. Next, while remaining still, they carried out each of the three RDS-TMC tasks several times until it was clear that they mastered these tasks sufficiently well.

Subsequently, participants drove to the starting point of the experimental route. They were guided along the experimental route by the experimenter to prevent them from being burdened by navigation. All participants drove this route four times, two times in the control condition and two times in the experimental condition. Half the participants started with two control drives at the experimental route followed by two experimental drives. This was reversed for the other half of the participants. After completion of the first experimental drive, baseline performance on the various tasks was obtained in a standing-still situation.

Following each of the 12 experimental driving situations, the experimenter, who was an experienced driving instructor, rated the safety of driving in that situation on a number of three-point rating scales. Half the participants drove in the morning (10 AM to 12:30 PM), whereas the other half drove in the afternoon (2:30 PM to 5 PM).

Alongside the experimental route, just in front of each experimental situation, inconspicuous markers were attached to light poles. These markers were used by the technician in the back of the car to trigger the onboard system that determined which task instruction was given to the participant. This ensured proper and consistent timing of the RDS-TMC tasks. Each task was performed while driving in the situations specified before.
Data Analyses and Design

Subjective safety ratings were given by the experimenter who was also a driving instructor. These items are presented in Table 2.11.2 and were derived from a standardized list and validated in earlier work (De Gier, 1980). A distinction was made between items referring mainly to vehicle control and items indicating interactions with other traffic participants. Each item was scored as being satisfactory, acceptable, or unsafe. An unsafe rating was given when a critical part of the task was not carried out at all (e.g., not looking at priority traffic) or in a poor, unsafe manner (e.g., braking exceptionally hard or swerving).

Table 2.11.3 presents an overview of all dependent variables. Video recordings were made of the participants’ heads and were later analyzed by one person. Because intersections had been selected where priority traffic could be seen only when the vehicle was close to the intersection, looking to crossing traffic was marked by a clear head movement. In right turn and yield situations, this allowed derivation of the hypothetical deceleration of the instrumented vehicle in case the driver suddenly detected a vehicle with priority at the moment of looking right and had to stop before entering the crossroad. (This usually did not occur.) In some straight driving situations, TLC and line crossing were assessed with a special-purpose lane-tracking device (Van der Horst & Godthelp, 1989).

The data were analyzed with a Task (task versus control) x Instance (3) x Replication (2) design for each type of situation. In addition, the various dependent variables were analyzed across all situations with a Task (2) x Situation (4) x Instance (3) x Replication (2) design. For frequency data, a logarithmic model was used in which Rating (satisfactory/acceptable versus unsafe) was an additional variable.

RESULTS

Objective and Subjective Measures of Driving

General. Table 2.11.4 shows the number of driving situations at which driving behavior was judged unsafe by the driving expert with respect to at least one of the various ratings. Driving was considered significantly more unsafe when performing any of the additional tasks than in the control condition (map versus control \( \chi^2(1) = 7.0, p < .01; \) speech versus control \( \chi^2(1) = \ldots \))
15.2, $p < .001$; filter programming versus control $\chi^2(1) = 53.3, p < .001$. Behavior was judged significantly more unsafe in the filter condition than in the map and the speech condition [$\chi^2(1) = 10.8, p < .001; \chi^2(1) = 6.0, p < .05$, respectively]. No difference was found in the number of unsafe ratings in the map and speech conditions [$\chi^2(1) = 0.8, p > .20$].

Across all situations, there were two types of driving behavior that were repeatedly considered unsafe. First, course keeping was generally rated more often unsafe in the task conditions than in the control condition [$\chi^2(1) = 17.6, p < .001$]. Planned comparisons showed that this was caused by course keeping in the filter-programming condition [$\chi^2(1) = 22.2, p < .001$] and not by course keeping in the map and speech conditions [$\chi^2(1) = 0.4, \chi^2(1) = 1.8, p > .10$, respectively]. In the map condition, course keeping was judged to be unsafe twice (out of 96 ratings = 2.1%), in the speech condition this happened 6 times (6.3%), and in the filter programming condition course keeping was considered unsafe in 22 cases (22.9%). In the control condition, it occurred only once (out of 288 ratings = 0.3%).

The second type of driving behavior that was repeatedly judged unsafe when using the RDS-TMC system was braking/deceleration. The major cause for these judgments was that participants did not sufficiently anticipate forthcoming braking actions rather than that they actually braked too hard. Braking/deceleration was considered more often unsafe in the task conditions than in the control condition [$\chi^2(1) = 10.2, p < .01$]. Braking behavior was considered unsafe 7 times (out of 96 = 7.3%) in the map condition, 4 times (4.2%) in the speech condition, and 18 times (18.8%) in the filter condition. In the control condition, poor braking occurred 6 out of the 288 times (= 2.1%). Planned comparisons of the individual in-vehicle tasks showed that unsafe ratings were given more often in the filter than in the control condition [$\chi^2(1) = 11.2, p < .001$]. The map and speech tasks did not yield more unsafe braking/deceleration ratings than the control condition [$\chi^2(1) = 1.0, \chi^2(1) = 0.8, p > .20$, respectively].

Right Turns. At right turns, drivers were supposed to look across their right shoulders to detect any bicycles and mopeds between the curb and the vehicle. Expert ratings indicate that participants frequently did not show this behavior in the task conditions [$\chi^2(1) = 6.9, p < .01$] (Table 2.11.5).

This reduction of looking in the proper direction was associated with a marginally significant increase in the number of times that mopeds and bicycles were hampered [$\chi^2(1) = 3.7, p < .06$]. Ongoing traffic was hampered 6 times (out of 72) in the task conditions (map: 1 = 1.4%, speech: 2 = 2.8%, filter programming: 3 = 5.2%), and not at all in the control condition. Course keeping significantly deteriorated while turning right in the task condition [$\chi^2(1) = 5.4, p < .05$]. Finally, safety of the braking actions was judged to suffer from performing an in-vehicle information task [$\chi^2(1) = 15.2, p < .001$].

According to the video analysis, participants did not look over their right shoulders on 46 out of 69 occasions in the task conditions (67%), whereas in the control condition this was the case for 38 out of 67 cases (= 57%; $\chi^2(1) = 1.4, p > .20$). The difference in these figures compared with the subjective ratings can be attributed to the fact that participants often used their mirrors to check for any mopeds or bicycles. This could not always be detected from the video. The percentages of hypothetical decelerations over 2 and 3 m/s² in case of another car's taking right of way did not differ significantly in task and control conditions.

General Rule Intersections. When approaching the general rule intersection, course keeping was judged as being poorer in the task conditions: Unsafe ratings were given 12 times (17%) in the task conditions, and 0 times in the control condition [$\chi^2(1) = 17.2, p < .001$]. Closer inspection of the data showed that out of the 12 occurrences of unsafe course keeping, 10 were in the filter-programming condition [$\chi^2(1) = 4.7, p < .10$]. Task condition had a marginally significant effect on safety judgments of braking and deceleration behavior at general rule intersections [$\chi^2(1) = 3.4, p < .07$]. Whereas 7 (9.7%) unsafe situations occurred in the task condition, there were 2 (2.8%) such situations in the control condition.

Video analyses showed that participants tended to look less in the direction of priority traffic in the task conditions (46 out of 72 = 64%) than in the
control condition (56 out of 72 = 78%; \( \chi^2(1) = 3.4, p < .07 \)). The percentages of hypothetical decelerations over 2 and 3 m/s² did not differ significantly in task and control conditions.

**Yield Intersections.** When approaching yield intersections from the secondary road, the expert ratings indicated that braking/deceleration was affected by the in-vehicle tasks (\( \chi^2(1) = 11.3, p < .001 \)) (Table 2.11.6). No other differences between conditions were found.

**Straight Driving.** Expert judgments showed that participants swerved more in the task conditions than in the control condition (\( \chi^2(1) = 5.5, p < .05 \)) (Table 2.11.7).

With respect to objective measures, driving performance was analyzed for the period that the driver was engaged in the in-vehicle tasks (i.e., between presentation of the message and the response). For the control condition, driving performance was analyzed for the same road segments as in the task conditions. Analysis of objective measures of steering indicated that the average interval between subsequent steering movements was lower in the task conditions, as compared with the control condition (from 0.91 s to 0.56 s; \( F(2.72) = 29.5, p < .001 \)). Subsequent Tukey testing showed that this effect was caused by the filter condition alone (map and speech: \( p > .20 \), filter programming: \( p < .001 \)). Speed, standard deviation of speed, and frequency that time-to-line crossing was below the critical value of 1.1 seconds (see Verwey, 1996) did not differ in task and control conditions.

**TABLE 2.11.6**

<table>
<thead>
<tr>
<th>Rating</th>
<th>In-Vehicle Tasks</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satisfactory</td>
<td>21</td>
<td>48</td>
</tr>
<tr>
<td>Acceptable</td>
<td>41</td>
<td>22</td>
</tr>
<tr>
<td>Unsafe</td>
<td>16</td>
<td>2</td>
</tr>
</tbody>
</table>

**TABLE 2.11.7**

<table>
<thead>
<tr>
<th>Rating</th>
<th>In-Vehicle Tasks</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satisfactory</td>
<td>51</td>
<td>99</td>
</tr>
<tr>
<td>Acceptable</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td>Unsafe</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>

The data suggest that safety was negatively affected in the task conditions, especially in the filter condition. Therefore, it is important to know for how long and how often participants looked at the RDS-TMC display. Table 2.11.8 shows various measures of looking behavior that seem to be related to the situation that behavior starts being unsafe.

**TABLE 2.11.8**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Glance Frequency (Range)</th>
<th>Average Time per Glance (s) (Range)</th>
<th>Total Glance Time (s)</th>
<th>Percentage Glances &gt; 1 s</th>
<th>Percentage Glances &gt; 2 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map</td>
<td>5.2 (3-12)</td>
<td>1.5 (1.0-2.7)</td>
<td>7.9</td>
<td>51</td>
<td>18</td>
</tr>
<tr>
<td>Filter</td>
<td>6.8 (4-10)</td>
<td>1.5 (1.0-2.2)</td>
<td>10.2</td>
<td>65</td>
<td>24</td>
</tr>
</tbody>
</table>

The results show that, according to safety judgments by the driving expert, safety was affected by the in-vehicle tasks and clearly more so for filter programming than for the map and speech tasks. In the filter-programming task, these effects were largely caused by poor course keeping and (poor anticipation of) braking and decelerating. Significant effects in the objective measures were found only as an increase in steering frequency when carrying out in-vehicle tasks at the straight inner-city road and a tendency to look less to the right at the general rule intersection in the filter condition. With respect to the development of a method for safety evaluation, it is interesting to note that according to the expert, interactions with other cars (adapting speed to other traffic, distance to headlight traffic, anticipation in general, giving priority, watching priority traffic) were hardly affected by the use of the RDS-TMC system. Bicycles and mopeds may sometimes be endangered in the right-turn situations.

**In-Vehicle Task Performance**

To assure that the in-vehicle tasks had been properly carried out, performance on these tasks was analyzed, too. Table 2.11.9 presents the occurrence of errors on the three RDS-TMC tasks. These data were analyzed with a driving versus remaining still \( \times \) map versus speech \( \times \) satisfactory/acceptable versus unsafe logarithmic model. This analysis showed that significantly more errors had been made with speech messages than with maps (\( \chi^2(1) = 15.4, p < .001 \)), but that the map versus speech \( \times \) driving versus remaining still interaction did not reach significance (\( \chi^2(1) = 0.9, p > .20 \)). This suggests that the difference between the map and speech presentation modes was related to task difficulty and not to interference with driving.
### Table 2.11.9

<table>
<thead>
<tr>
<th></th>
<th>Map</th>
<th>Speech</th>
<th>Filter</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right turns</td>
<td>3 (13%)</td>
<td>7 (25%)</td>
<td>6 (25%)</td>
<td>16 (22%)</td>
</tr>
<tr>
<td>General rule intersections</td>
<td>0 (0%)</td>
<td>9 (38%)</td>
<td>6 (25%)</td>
<td>15 (21%)</td>
</tr>
<tr>
<td>Yield intersections</td>
<td>0 (0%)</td>
<td>4 (17%)</td>
<td>3 (13%)</td>
<td>7 (10%)</td>
</tr>
<tr>
<td>Straight driving</td>
<td>1 (4%)</td>
<td>1 (4%)</td>
<td>2 (6%)</td>
<td>4 (6%)</td>
</tr>
<tr>
<td>Remaining still</td>
<td>8 (6%)</td>
<td>8 (17%)</td>
<td>12 (48%)</td>
<td>34 (33%)</td>
</tr>
<tr>
<td>Total</td>
<td>7 (5%)</td>
<td>20 (26%)</td>
<td>18 (13%)</td>
<td>54 (13%)</td>
</tr>
</tbody>
</table>

### Conclusion

The present study sheds some light on two questions: How can safety be measured, and how should the human-machine interface of in-vehicle information systems be designed? As to the first issue, it turns out that subjective measures were far more sensitive to what happened when the driver was using the in-vehicle information system than were the objective measures of driving. Subjective ratings that showed the clearest effects, at least in the most demanding task condition (i.e., the filter condition), were the ones on course keeping and (anticipating) braking and accelerating. Ratings on the other scales also showed effects of the in-vehicle tasks, but not as consistently across the various situations. Of the objective measures, only steering frequency at straight inner-city roads increased with filter programming, and participants tended to look less to the right at general rule intersections. The other measures listed in Table 2.11.3 appeared not to be sensitive measures for reductions in driving safety. The fact that increased steering frequency coincided with reduced safety ratings on the straight road segments suggests that steering frequency is an indicator for safety reductions in such situations.

These subjective and objective indicators for unsafe behavior are remarkable because participants had been instructed to postpone in-vehicle tasks if they thought safety would be affected. This suggests that participants could not sufficiently predict the safety effects of their interactions with the in-vehicle system. From a safety point of view it might have been better if they had waited until the vehicle was in a less demanding driving situation.

The expectation that certain subjective and objective indicators for safety effects would covary was not fulfilled. The finding that safety was clearly affected according to subjective measures, and hardly according to the objective measures, might either mean that subjective measures were influenced by misjudgments and biases of the driving expert or that the objective measures were not sensitive enough. In the absence of a safety criterion, this issue is hard to settle. However, informal reports by the driving expert and the technician underline that dangerous situations did occur, even when the objective measures did not demonstrate this. A few times, the driving instructor was even required to take control. I think that, despite all problems associated with subjective ratings, this method does yield useful indications for reductions in safety.

The fact that hardly any objective indicators for safety effects were found is probably caused by the fact that in field studies, objective measures are subject to variations caused by momentary traffic conditions and individual differences. For example, it was noted that drivers sometimes did not look over their right shoulders at right turns. However, it turned out that driving was perfectly safe because drivers had used their mirrors long in advance and started driving near the curb to keep bicycles and mopeds from riding between the vehicle and the curb. Objective measures do not clearly reflect such alternative behaviors that can not always be anticipated by the researcher. Subjective judgments are probably much less subject to these variations in measurements because the human observer acts as a noise filter. Unimportant events that affect objective measures do not affect subjective measures. Despite all problems associated with subjective safety ratings, I conclude that expert judgments on standardized rating lists should be preferred for safety evaluations of in-vehicle information systems.

If we accept that the present subjective safety results are reliable reflections of “true” safety effects, then it is also possible to propose some guidelines with the respect to in-vehicle information systems. The data make sufficiently clear that programming an RDS-TMC filter affects driving safety to a considerable extent. Handling an in-vehicle information system while driving appears to be a dangerous task, even when there is no (explicit) time pressure to finish the task. It seems that participants underestimated the safety effects of filter programming. The reason that filter programming was so detrimental to driving safety may lie in the visual as well as in the manual workload of filter programming (Verwey, 2000; Wickens, 1984). The findings with the filter task suggest that handling a system that requires a sequence of actions and of readings from a display is not acceptable from a safety point of view. The glance data indicate that this holds for tasks that take total viewing times as long as 10 seconds.

Despite these serious safety effects of filter programming, it should not be forgotten that driving behavior was also judged to be unsafe three to four times as often with a visual map display and with speech messages as when driving without an in-vehicle task. Notably, the safety effects in the speech condition did not significantly differ from those in the map condition. It has not been demonstrated before that the safety effects of mentally loading tasks may actually be comparable to those of visually loading tasks. An expla-
nation for that fact that speech had such an unexpectedly large effect on safety is that drivers could not pay attention to the additional task when they wanted to. With visual messages, this is usually much less of a problem. Hence, in the design of in-vehicle information systems, the choice between visual and speech messages is one that still needs careful consideration. The high error rates in the speech condition while remaining still demonstrate that for the present type of information, speech information was simply less suited than visual information. We can learn from this study that visual information may sometimes be preferable over speech messages. However, the data also show that the visual messages we used and that required as much as 7 seconds total looking time affected traffic safety. This safety effect is not acceptable, and total looking times should in any case remain below 7 seconds.

Taken together, the present results suggest that evaluating negative safety effects of in-vehicle information systems should be based on the use of a standardized safety rating list that should focus on control aspects like swerving and braking and decelerating. Steering frequency might be a useful objective safety measure while driving straight. With respect to the design of in-vehicle information systems, the data show that for some types of information, visual information is better suited from a safety point of view than are speech messages. Finally, driving safety is jeopardized when the interaction between the driver and the system involves 10 seconds or more total looking time and when inspection of a visual display alone lasts 7 seconds or more total looking time.

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REFERENCES
