KogWis 07

Fachrichtung Psychologie

Gesellschaft für Kognitionswissenschaft

Cognitive Science 2007

Proceedings of the 8th Annual Conference of the Cognitive Science Society of Germany.

Zimmer, H. D.
Frings, C.,
Mecklinger, A.
Opitz, B.
Pospeschill, M.
Wentura, D. (Eds.)

Saarbrücken

URL: http://psydok.sulb.uni-saarland.de/volltexte/2008/1185/

URN: urn:nbn:de:bsz:291-psydok-11856

Cognitive Science 2007. Proceedings of the 8th Annual Conference of the Cognitive Science Society of Germany.

Content

Weiß, Petra[1]; Pfeiffer, Thies [2]; Schaffranietz, Gesche[1] & Rickheit, Gert[1] 1 Fakultät für Linguistik und Literaturwissenschaft/SFB 673 2 AI & VR Lab, Technische Fakultät Universität Bielefeld	Coordination in dialog: Alignment of object naming in the Jigsaw Map Game.
Baumotte, Henrike [1 2]; Müller, Horst M. [1] & Dogil, Grzegorz[2] 1 Experimental Neurolinguistics Group, University of Bielefeld, Germany 2 Experimental Phonetics Group, Institute for Natural Language Processing, Univ. of Stuttgart, Stuttgart	Lexical access from spectrum? Phonetic properties of proper names and common nouns in German and Mandarin Chinese
Baumotte, Henrike & Dogil , Grzegorz Experimental Phonetics Group, Institute for Natural Language Processing, Univ. of Stuttgart, Stuttgart	State of the art of phonetic language aptitude linking phonetic as well as phonological models to empirical neuroimaging (neurolinguistic) research
Lewandowski, Natalie[1]; Jilka[2], Matthias; Rota[1], Giuseppina; Reiterer[3,1], Susanne & Dogil[1], Grzegorz 1 Experimental Phonetics Group, Univ. of Stuttgart; 2 Institute for Linguistics, Anglistics, Univ. of Stuttgart; 3 Dept. of Neuroradiology, Section for Experimental MR of the CNS, Univ. of Tübingen	Phonetic convergence as a paradigm of showing phonetic talent in foreign language acquisition. Institute for Natural Language Processing,
Bermeitinger, Christina; Frings, Christian & Wentura, Dirk Cognitive Psychology – Cognition and Action Unit, Saarland Univ., Saarbrücken	Repeated masked semantic priming with new results: ERPs of a negative semantic priming effect.
Tenbrink, Thora SFB/TR 8 Spatial Cognition Univ. of Bremen, Bremen	Space, time, and the use of language: An investigation of relationships.

Strobach[1], Tilo; Frensch[1], Peter A.& Schubert[2], Torsten Dept. of Psychology, General Psychology, Humboldt Univ., Berlin; Dept. of Psychology, Experimental Psychology, Ludwig-Maximilians Univ., München	The temporal stability of skilled dual-task performance.
Aschersleben[1], Gisa & Müsseler[2], Jochen 1 Dept. of Psychology, Developmental Psychology Unit, Saarland Univ., Saarbrücken; 2 Psychology Dept., RWTH Aachen Univ., Aachen	Dual-task performance while driving a car: Age-related differences in critical situations.
Polushkina[1], Svetlana; Kühnberger[2], Kai-Uwe & Gust[2], Helmar 1 Research Training Group "Feedback Based Quality Management in eLearning" Univ. of Technology, Darmstadt, Darmstadt; 2 Institute of Cognitive Science, Univ. of Osnabrück, Osnabrück	Solving systems of equations by analogy: An experiment and a model.
Weiler[1], Daniel; Läer[1], Leonard; Engel[2], Andreas K. & König[1], Peter 1 Institute of Cognitive Science, Dept. Neurobiopsychology, Univ. of Osnabrück, Osnabrück; 2 Dept. of Neurophysiology and Pathophysiology, Univ. Medical Center Hamburg-Eppendorf, Hamburg	Unsupervised learning of reflexive and action-based affordances to model navigational behaviour.
Buechel, Eva; Vogt, Annamarie & Opwis, Klaus Dept. of Cognitive Psychology and Methodology, Univ. of Basel, Basel	Pseudoneglect as a function of hand use and line length.
Brinkmann, Thorsten & Zimmer, Hubert D. Brain and Cognition Unit, Dept. of Psychology, Saarland Univ., Saarbrücken.	Contributions of modality-specific brain regions to working memory and long-term memory: An ERP study.

Dual-task performance while driving a car: Age-related differences in critical situations

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Dual task conditions are especially demanding for older drivers. For example, while driving a car the driver has to process additional information (e.g. from the navigation system) and to react in an appropriate way. Especially under demanding driving conditions impairments in reaction time have to be expected. One important factor is the cross-task compatibility, that is whether the information presented in the secondary task provides information, which is compatible or incompatible to the primary task. First results indicate that effects of cross-task compatibility depend on the relevance of the driving situation and on the direction of the response that has to be performed in the primary task, and not so much on the position at which the information is presented.

Background

Dual task situations are ubiquitous, at home as well as at work. Especially modern information technologies often require the coordination of different activities. For example, while driving a car the driver has to process additional information (e.g. from the navigation system or from the mobile phone) and to react in an appropriate way. This is especially the case for professional drivers like taxi drivers or lorry drivers. Under less demanding driving conditions, e.g. slow driving with low traffic density, the coordination of the primary task (driving the car) and the secondary task (manipulating the navigation system) might be relatively easy. However, under demanding driving conditions and especially in critical traffic situations, impairments in reaction times and driving errors can be expected. Thus, the aim of the present study was to analyze the impairments in performance that have to be expected under dual task conditions in critical traffic situations. We were especially interested in the age-related differences in performance.

Since the 1930s dual-task performance is an important topic in cognitive psychology (Telford, 1931). In a typical dual-task experiment, participants are required to react as fast as possible to two stimuli being presented in close succession. For example, participants are instructed to press a left/right key (R1) in response to a high/low tone (S1) and to say „blue“ or „yellow“ (R2) in response to a blue or yellow stimulus (S2). Under conditions with a short time interval (stimulus-onset asynchrony, SOA) between the presentation of S1 and S2 (i.e. S2 is presented

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when response preparation and production of R1 has not yet been completed), dramatic increases in reaction time and errors in the secondary task (S2-R2) are observed.

Until recently these impairments in performance were mainly explained by capacity limitations at the response selection stage (for an overview see Pashler, 1994). It had been assumed that two reactions could not be selected simultaneously because the central stage of response selection is limited to process one event at a time. As a consequence, response selection of the secondary task has to wait until response selection of the primary task had been completed (so-called „locus-of-slack“ logic, see Fig. 1). More recent dual-task studies found evidence that processing S1 not only impairs the selection of R2, but also impairs perceptual encoding of S2. Using a go/no-go manipulation in the primary task Müsseler and Wühr (2002) could show that performance in the secondary task is impaired even under conditions under which only identification of the stimulus but no response selection is required in the primary task (see also Jolicœur, 1999). Moreover, by introducing compatibility relationships between tasks (for an overview see Lien & Proctor, 2002), it was shown that compatibility information could successfully bypass the response-selection bottleneck (Hommel, 1998; see also Müsseler, Koch, & Wühr, 2005; Müsseler, Wühr, & Umiltà, 2006). Based on these findings, it has to be assumed that sensory, cognitive as well as motoric processes on a central level are susceptible to interference in dual-task situations.

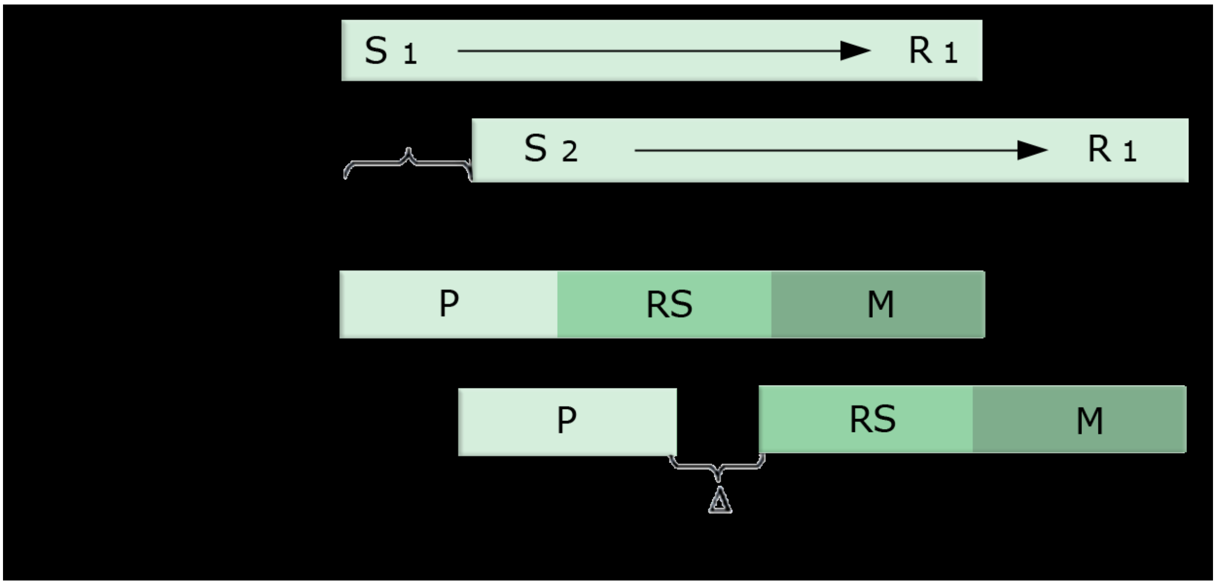

Fig. 1 (A) Basic dual-task situation in the psychological refractory period paradigm (prp task). Participants are required to react to two successively presented stimuli (S1 and S2) with two different responses (R1 and R2). (B) Typical explanation based on the locus-of-slack logic. Response selection (RS) of the second task has to wait until RS of the first task terminated. As a result reaction times in the second task are lengthened by Δt (P = perceptual processing, RS = response selection, M = motor processes, SOA = stimulus onset asynchrony).

Concering dual-task effects in driving situations, it has been shown in various studies that, for example, using a mobile phone when driving distracts the driver (for a recent overview see Dragutinovic & Twisk, 2005): It not only causes physical distraction (when drivers have to simultaneously operate their mobile phone and operate their vehicle) but also cognitive distraction. Cognitive distraction occurs when a driver has to divert part of his/her attention from driving to the telephone conversation. However, it has been shown in laboratory research (see previous paragraphs) that the ability to divide one's attention between two simultaneous tasks is limited. Mobile phone use while driving could, therefore, negatively affect driving performance. Consequently, the results of several studies strongly suggest that using a mobile phone while driving can increase the risk of being involved in a road crash up to four times (Redelmeier & Tibshirani, 1997). In a simulated driving task study, Strayer and Johnston (2001) showed that telephone conversations resulted in a significant increase in reaction time to simulated traffic signals. Moreover during conversation, participants missed twice as many signals. Similarly, Tornros and Bolling (2005) reported impaired reaction time as well as increased amount of errors both during mobile phone dialing and conversation in a peripheral detection task, in which participants had to respond to a light stimulus that appeared in the participant's periphery with respect to the main driving focal point. In general, the conclusions of these studies are that the use of mobile phones negatively affects different aspects of a driver's performance: Reactions to traffic signals are slower, braking reactions are slower with shorter stopping distances, drivers miss more important traffic signals, they are inclined to riskier behaviour like accepting shorter gaps or making fewer speed adjustments or adjustments to dangerous road conditions.

In the present context, it is important to note that performance in dual-task situations decreases and susceptibility to interference in compatibility tasks increases in elderly people (Verhaegen, Steitz, Sliwinski, & Cerella, 2003; Pick & Proctor, 1999; Spieler, Balota, & Faust, 1996). It has been demonstrated in many experimental studies that dual task conditions are in particular demanding for elderly people. The age-related increase in interference has been commonly explained by a general slowing of cognitive processes, especially of attentional processes and executive functioning (e.g. Hartley & Little, 1999; Reuter-Lorenz, 2002; Salthouse & Somberg, 1982; but see also Lindenberger & Baltes, 1994). Based on a meta-analysis of 34 studies on the effects of age on dual-task performance Riby, Perfect, and Stollery (2004) conclude that with increasing age tasks with a substantial controlled processing component showed greater dual task impairment than tasks that were relatively simple or relied on automatic processing. The latter tasks could be performed without a substantial interfering influence from the secondary task.

In many cognitive functions that are important for driving a car a reduced performance can be found with increasing age. A significantly reduced rate of information processing and, thus, an increase in general reaction time can already be observed at the age of 45 years (Stenneken, Aschersleben, Cole, & Prinz, 2002; Stern, Oster, & Newport, 1980). Especially with increasing complexity of the tasks disproportionate impairments in the performance of elderly people are obtained (Dobson, Kirasic, & Allen, 2002; Kliegl, Krampe, & Mayr, 2003; Li, Lindenberger, Hommel, Aschersleben, Prinz, & Baltes, 2004). The ability to discriminate relevant from irrelevant information is most impaired in elderly people if they have to perform the task under time pressure (Plude & Hoyer, 1986). However, the ability to select information in a fast and efficient way is especially important when driving a car.

Thus, a whole range of psychological (e.g. reduced memory span, reaction time, divided attention, sustained attention) as well as physiological (reduced vision and hearing abilities, reduced fine motor skills) functions are impaired with increasing age, which should have a negative influence on the roadworthiness. Nevertheless, accident statistics draw a different picture (Cohen, 2001). The risk to cause an accident is rather high immediately after the successful application for a driving license, then declines (between the age of 18 to 25 years) and is constant until the age of 65 years. Only after the age of 65 years, risk to cause an accident slightly increases again (HUK-Verband, 1994). The reasons for this somewhat unexpected pattern might be found in the use of compensatory strategies in elderly people. Older drivers avoid critical situations like rush-hour traffic, driving at night or under bad weather conditions (Hartenstein, 1995; Stutts, 1998). They do not drink and drive, use well-known routes and drive at slower tempi (Cox & Cox, 1998). Finally, a shift towards more serial operation of controls can be observed that probably represents a compensatory mechanism allowing older drivers to maintain their level of performance (Hakamies-Blomqvist, Mynttinen, Backman, & Mikkonen, 1999). In sum, situations requiring an increased level of cognitive effort are avoided. The most frequent causes of an accident in older drivers are driving errors made at intersections and junctions, rear-end collisions and overlooked traffic signs (Cox & Cox, 1998; Praxenthaler, 1995). This again suggests an increase of accidents in situations with cognitive overload. On the other hand, older drivers only rarely cause accidents as a result of driving while intoxicated, because of speeding or inadequate overtaking (Praxenthaler, 1995).

It seems that older drivers develop compensatory strategies that allow them to compensate for their sensory, motoric as well as cognitive shortcomings (e.g. Sommer, Falkmer, Bekiaris, & Panou, 2004). Older drives do not necessarily drive worse, however, as it is not always possible to avoid problematic and demanding traffic situations (e.g. driving at night) elderly people drive with higher cognitive load. Thus, it is important to study the influence of this fact on reactions, in critical situations in which a coordination of different tasks is required. As critical situations cannot always be avoided and, therefore, elderly people might also get into driving situations, in which their compensatory strategies do not work, the aim of the present research is to, first, determine those situations that are especially impairing for elderly people and, second, to make these situations less dangerous by suggesting appropriate designs.

First Results

While driving a car the driver often has to immediately react to visual information that is spatially localized (e.g. avoiding obstacles that suddenly appear at the right side of the road). From compatibility research it is well known that speed as well as accuracy of a spatial reaction is influenced by the spatial location of the imperative stimulus. A stimulus that is presented ipsilateral (at the same side at which the reaction is required) results in faster responses and less errors than a stimulus that is spatially non-corresponding with the required reaction. In classical compatibility theories, this pattern of results is explained by an automatic activation of the corresponding reaction that in the case of an incompatible situation has to be inhibited first before the correct response can be performed (Kornblum, Hasbroucq, & Osman, 1990). The question about the influence of compatibility effects in driving situations has been mostly ignored in research. Exceptions are studies by Wang and colleagues. Wang, Proctor, and Pick (2003) analyzed the influence of warning signals in a collision avoidance system on steering responses. Participants were told that tones presented to the left or right ear were warning signals from a collision avoidance system. They were instructed that the signals indicated the location of the danger source, from which they were to turn away, or the escape direction, toward which they were to turn. Spatial compatibility effects predict that it would be most beneficial to have the tone correspond to the desired response direction. Due to the stimulus valence of warning signals - you typically turn away from sounds created by hazards – an avoiding behavior, i.e., turning away from the warning tone, might be more compatible than responding toward it. Wang et al.'s (2003) results showed a typical spatial compatibility effect, suggesting that spatial compatibility was the primary factor influencing performance. More recently, though, Wang, Pick, Proctor, and Ye (2007) found that when participants were engaging in a simulated driving scenario, they were faster at turning away from the collision avoidance signal rather than toward it. This latter result suggests that, when driving, humans' responses to warning signals may follow valence compatibility principles – and not the principles of spatial compatibility. However, response latencies in this study were long – in the range of 4 seconds – because participants typically waited until they perceived the encroaching vehicle to respond, implying that the results may have been due to participants directing attention in the direction of the impending threat to facilitate its detection.

The aim of our first experiments was to analyze whether a critical situation while driving a car (e.g. a pedestrian suddenly entering the road from the left or right side) results in a reversal of classical compatibility effects, similar to what had been reported by Wang et al. (2003). Classical compatibility theories would imply that first an automatic activation of the corresponding reaction (i.e. in the direction of the dangerous stimulus) takes place, which then has to be inhibited before the correct response can be selected. The question is whether this automatic activation of the ipsilateral response is the same in driving situations.

In the first five experiments 144 participants aged between 18 und 65 years took part. In a darkened room participants were seated in a car seat in front of a steering wheel and foot pedals. Short videos were presented via beamer. In all experiments a taxi driver scenario was realized. In a simulated driving situation, participants watched short videos, in which they approached an intersection and a pedestrian entered the road from the left or the right side either calling the taxi by waving the arm or causing a critical situation by turning the back towards the driver. Participants were instructed to react as fast as possible by turning the wheel clockwise or counterclockwise either towards the location of the person or away from the person. Each trial was started by pressing a foot pedal.

In the first experiment, we tested whether the assumption of automatic ipsilateral response activation also holds in critical driving situations or if the compatibility effects depend on the meaning of the stimuli. Reaction time in the driving situation was compared with a control condition, in which neutral stimuli (diamond and square) were presented laterally. Here, participants also had to react as fast as possible by turning the wheel clockwise or counterclockwise. This first experiment was conducted with a group of young participants (mean age 21 years). Different to what had been predicted by classical compatibility theories reaction time in the critical situation (avoiding reaction; incompatible condition) was shorter than reaction to the person calling a taxi (compatible condition). In the control condition with neutral stimuli the usual compatibility effect (shorter reaction times with ipsilateral reaction) was observed. Thus, in critical situations the compatibility effects seem to be inverted indicating that the meaning of the stimuli is important (Müsseler, Aschersleben, Arning & Proctor, 2007; Exp. 1). This interpretation was supported by the following experiments. Under conditions under which the pedestrians were presented peripherally, they were probably no longer interpreted as being dangerous stimuli and, as a consequence, the usual compatibility effect was observed (Müsseler et al., 2007; Exp. 2). In a third experiment, we were able to replicate the results obtained in the first experiment and also compared them with the results of a group of older drivers (mean age 62 years; Aschersleben, Arning, & Müsseler, in prep.). As expected we observed longer reaction times in the elderly participants, however, there was no interaction between age and compatibility indicating that the compatibility effect was not increased in the group of older drivers (see Fig. 2). One possible explanation for this somewhat unexpected result might be the fact that older drivers also are more experienced in driving.

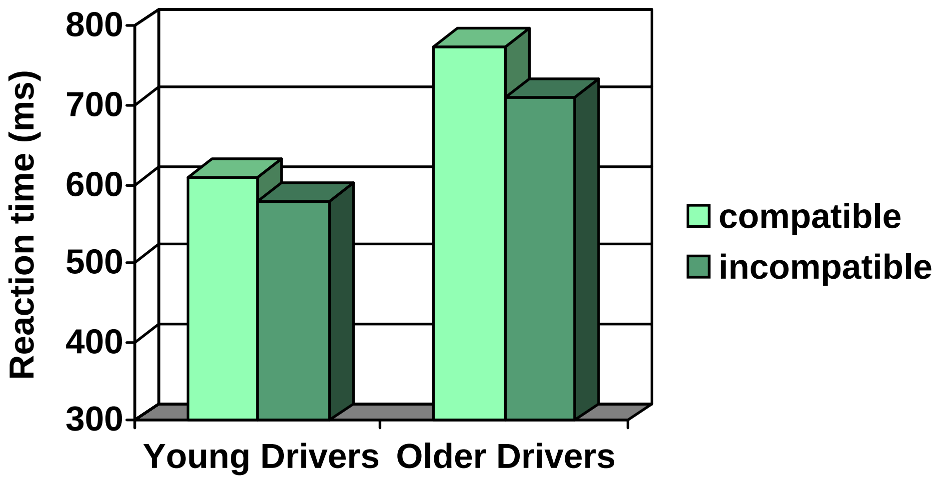

Fig. 2 Reaction times (in ms) for the two tested aged groups and the compatible vs. incompatible condition.

Next, we extended the experimental design to analyze the influence of dual-task situations in car driving. Participants heard a spoken message from the navigation system just before the imperative stimulus (pedestrian) was presented. Thus, the primary task required to react with a left or right steering-wheel response to a pedestrian suddenly entering the street whereas the secondary task required listening (and later react) to the message from the navigation system. As this message consisted in an instruction concerning the driving direction („turn left (right)“) and therefore also contained spatial information, we were mainly interested in cross-task compatibility effects between the primary and the secondary task. Results indicate that when the pedestrian enters from the right (left) side, a right (left) message from the navigation system impairs performance as it conflicts with the left (right) steering-wheel response to avoid hitting the pedestrian. In other words, superior performance is observed when the spoken message and the direction of the steering-wheel response corresponded than when they do not. When testing a group of elderly people, we observed increased reaction times as well as the cross-task compatibility effect - but again no interaction between age and compatibility, indicating that the compatibility effect was not increased in the group of older drivers (Aschersleben et al., in prep.). To test the assumption that the decreasing performance with age in the dual-task situation is compensated by expertise in the elderly people, we tested professional drivers. First results indicate a reduced cross-task compatibility effect in a group of elderly professional drivers indicating the indeed two factors might be interacting here: age and expertise.

Future Prospects

The aim of the present project is to analyze the specific cognitive load of drivers in dual task situations. First results indicate that in critical situations a clear influence of the secondary task (e.g. a message from the navigation system) on the reaction time in the primary task. In further experiments we will analyze the influence of different stimulus modalities (e.g. auditory vs. visual) of the secondary task. Moreover, until now we only studied so-called functionally dependent tasks, that is the information provided by the secondary task was relevant for the primary task. If the same pattern of results can be obtained in functionally independent tasks (e.g. manipulation of the car radio) is an empirical question, which will be analyzed in further studies.

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