Fatigue while driving in a car simulator:

Effects on vigilance performance and autonomic skin conductance

Heidi Inkeri

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University of Jyväskylä

Department of Psychology

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Heidi Inkeri

Instructor: Narciso González Vega

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Abstract

In this vigilance research the effect of fatigue on driver's voluntary reaction times (RT) and autonomic skin conductance (SC) was studied. Participants (n=17) drove approximately 3 hours in a simulator responding simultaneously on a peripheral visual vigilance task (PVVT). RTs were classified into 5 quintiles according to their latency. Also misses and misclassifications were explored. Results indicated that RTs increased linearly over time. SC amplitudes differed significantly between RT quintiles. Vigilance performance was the best when arousals were frequent but their magnitude remained relatively low. Frequent and high amplitude arousals in turn were associated with the worst performance. Results suggest that autonomic SC and voluntary RT could be combined to reveal driver's fatigue and vigilance performance more consistently than either measure alone.

Keywords: vigilance, fatigue, autonomic, skin conductance (SC), reaction time (RT), arousal

Tiivistelmä

Tässä vigilanssitutkimuksessa selvitettiin väsymyksen vaikutusta kuljettajan tahdonalaisiin reaktioaikoihin sekä autonomiseen ihokonduktanssiin. Koehenkilöt (n=17) ajoivat noin 3 tuntia simulaattorissa reagoiden samanaikaisesti perifeeriseen visuaaliseen vigilanssitehtävään (peripheral visual vigilance task = PVVT). Reaktioajat luokiteltiin pituutensa perusteella 5 ryhmään (quintile = qnt). Lisäksi tarkasteltiin menetettyjä sekä väärinluokiteltuja ärsykkeitä. Tulokset osoittivat reaktioaikojen kasvavan lineaarisesti ajan myötä. Ihokonduktanssiamplitudit erosivat merkittävästi eri reaktioaikaryhmissä. Vigilanssisuoriutuminen oli parasta kun arousaleja tapahtui tiheästi mutta niiden voimakkuus pysyi suhteellisen matalana. Tiheästi tapahtuvat ja korkea-amplitudiset arousalit puolestaan yhdistyivät huonoimpaan suoriutumiseen. Tulokset ehdottavat, että autonominen ihokonduktanssi ja tahdonalainen reaktioaika voitaisiin yhdistää kuljettajan väsymyksen ja vigilanssisuoriutumisen paljastamiseksi laajemmin kuin pelkällä toisella mittarilla tutkittuna.

Avainsanat: vigilanssi, väsymys, autonominen, ihokonduktanssi (SC), reaktioaika (RT), arousal

Table of contents

Glossary

Alertness = wakefulness, the level of being able to react. Alertness, arousal and activation each refer to a continuum of energy mobilization between come or deep sleep to the high excitement and kind of agitation (Dawson & Schell, 2002).

Arousal = a ”waking up” reaction of the brain and body with multiple psychological and physiological consequences (Kalat 2007; Lyytinen 1984).

Autonomic Nervous System (ANS) = involuntary nervous system that attends controlling many internal glands and organs, like heart, blood vessels, sweat glands and digestive organs. Two subdivisions, parasympathetic and sympathetic, have contradictory roles in human body and in determining the activity of controlled organs. Sympathetic division mobilizes body resources to prepare the organism to respond e.g. by increasing palmar sweating. Parasympathetic division reduces heart rate and increases digestive activity and thus aims to store energy. (Dawson & Schell, 2002).

Fatigue = drowsiness, feeling sleepy.

Orienting reflex or response = a response to any novel or significant stimulus excluding aversive ones. The shift of attention and facilitation of stimulus processing are though to be engaged to it. Inter alia palmar skin conductance increases transiently. (Dawson & Schell, 2002).

Orienting the focus of attention = consciously focusing attention towards a certain target. May include disengaging attention from some other object.

Vigilance = sustained attention. The form of attention that makes us possible to maintain our goals over time also in monotonous environments where arousing stimuli may be rare (Blakeslee 1979; Parasuraman, 2000; Kuikka, Pulliainen, & Hänninen, 2001).

1. Introduction

1.1. Towards safer road traffic

Driving a car is an essential part of many people's lives today in industrial countries. At the same time several people get killed yearly in traffic accidents. In Finland the number of the most fatal accident type, encountering accident, increased again in 2007. Running off the road accident was the second most fatal accident type (Liikenneturva, 2007, 2008). These crash types represented clearly the major reasons for losing lives on road traffic and can be considered resulting in a way or another from driver's inattention or inability to consider situational factors often produced by fatigue. The risk for fatigue increases especially outside the population centre on monotonous roads and long-distances because of slight stimulation. Along reduced alertness, driver's behaviour tends to change and inter alia reaction times (RT) to increase causing an immediate risk for safe driving (Ting et al., 2008). Also autonomic nervous system's (ANS) activity changes, affecting among other things on its sensitive measure, skin conductance (SC) (Parasuraman & Davies, 1984). ANS operation does not have direct observable effects on driving performance, but it has major effects on driver's physiology which in turn may be connected with behaviour and sensations of sleepiness.

As the use of cars is not going to decrease soon the aim to prevent car accidents should be part of road planning and vehicle equipment. Increasing awareness of fatigue-related accidents and developing effective ways to manage it should concern drivers, industry and governments (Dinges, 1995; Ting, Hwang, Doong, & Jeng, 2008). Finland's government made a principle decision in 2001 to reduce the number of people getting killed on road traffic accidents till year 2025 to be less than 100 while in 2007 it still was 380 (Liikenneturva, 2008; Liikenne- ja viestintäministeriö, 2006). Understanding the reasons for accidents and studying the field are preconditions to reach the goal to save human lives on road traffic.

Reliable evaluation of the effect of vigilance decrement on car driving requires a car simulator environment because of the unique nature of driving. In every condition drivers are required to monitor their own driving and the surrounding traffic. Sudden events in the environment must be perceived, react and be able to flexibly change one's own plans if needed. Also speed and other technical issues must be under continuous control, even with automatic speed controller regardless of driver's alertness state. This research was part of the project *Monitoring Driver's Alertness on a Driving Simulator* aiming to develop scientifically tested on-line procedures to monitor and reveal the starting and progressive growth of sub-optimal alertness or readiness states on the driver that interfere with safe driving. The purpose was to study the relationships between behavioural and physiological variables in order to establish which ones predict deteriorated driving performance better. The aim of this research was to study driving performance through a RT task and autonomic SC reactions in vigilance task conditions for approximately three hours in each participant (n=17). In real-life conditions, the driver is required to perform many parallel activities like reacting, monitoring the road, perceiving relevant objects and controlling the steering wheel and speed. These simultaneous activities are preconditions for safe driving. Combining behavioural and physiological data can provide a richer approach to evaluate performance degradation in vigilance conditions.

1.2. Vigilance and decrement

Humans need ability to sustain attention in several daily activities. One of the most familiar examples is car driving: maintaining attention over long periods of time is required also in circumstances where arousing stimuli like other cars, are rare. This kind of sustained attention is called vigilance. It enables to maintain the driving task goals over time also in monotonous environments (Blakeslee 1979; Parasuraman, 2000). The study of the need for vigilance study began during World War II. It was noted that enemy planes were detected more poorly on the radar after a short period from starting point of a watch (Andreassi, 2007). Typical vigilance tasks require that the person maintains attention to detect infrequent and unpredictable events (Parasuraman, 2000). Mackworth (1950) was the first ones to investigate vigilance in humans with his clock test (Dember & Warm, 1979). The main idea of his, as other vigilance tasks', is that the observer must maintain attention to detect deviant events. Usually observers perform tests alone and their responses have no effect on infrequently and periodically occurring stimuli (Dember & Warm, 1979). In car driving, this is very much the case: drivers can not really affect on traffic around them, but they need to be alert enough to react also on sudden, unpredictable events. For instance in professional truck or bus driving it is essential to be able to shift attention and make fast decisions even after long-lasting, monotonous monitoring (Kuikka, Pulliainen, & Hänninen, 2001). If alertness declines below an optimal level, the ability to act fast and efficiently decreases and the risk of accidents increases (Kuikka, Pulliainen, & Hänninen, 2001).

Vigilance can be considered a primitive form of attention enabling an organism to alertly explore its environment and thus allowing it to learn, adapt and survive (Parasuraman, 2000). Mackworth (1969) points out that detecting change and danger of the environment has been a vital ability in evolution contributing survival. Today vigilance enables many perceptual and cognitive functions of a human (Parasuraman, 2000). Vigilance can also be considered a special form of attention maintenance where alertness must remain at a certain level to detect particular rare stimuli that require reacting (Kuikka, Pulliainen, & Hänninen, 2001). Vigilance has been considered one of the three processes of attention among selection and control (Parasuraman, 2000). Selection is needed because organisms are limited in processing many parallel stimuli. Control refers for instance to the ability to maintain and temporarily stop attention to respond to other, more important stimulus or processing many simultaneous targets (Parasuraman, 2000). Another approach to attentional processes comes from Posner (1990). His three processes of attention include orienting, target detection and alerting. Alerting refers to maintaining alert or vigilant state and is thus needed in vigilance tasks correspondingly to the vigilance (Posner, 1990). Detecting targets under conscious processing again requires executive functions of a human (Posner, 1990). In car driving all forms of attention are employed: sustaining attention, executive functions and orienting attention towards relevant objects.

Along prolonged time drivers are less able to use their senses to drive in a safe manner. Attention, a vital factor for driving performance, typically suffers over time in prolonged driving and this is called vigilance decrement (Parasuraman, 2000). There are many reasons for decrement but all result in the same phenomenon closely related to fatigue. One explanation are the diurnal variations in attentional processes. Lenne, Triggs and Redman (1998) found that driving performance measured in a simulator was the worst very early in the morning (0600) and night-time at 0200 and there was also an early afternoon dip. There are consistencies in Finland's accident statistics with these findings. (Liikenneturva, 2008). Effects of circadian rhythms on alertness were visible also in Sagberg's (1998) study of insurance company customers: drowsiness or reduced alertness was clearly emphasized in night-time and running off the road accidents and those occurring after 150 km drive.

Excessive time of driving is inevitably a serious threat for safe driving as inter alia RTs, sleepiness rate and unstable driving style are increasing (Ting et al., 2008). There are different views when performance begins to suffer and which is the limit for safe driving. Already after 20-25 minutes driving on monotonous environment, driver may perform according to a fatigue-related pattern of behaviour, like greater steering wheel movement (Thiffault & Bergeron, 2002). It has also been speculated that after the first half an hour attention begins to suffer (Kuikka, Pulliainen, & Hänninen, 2001) and performance clearly declines (Dember & Warm, 1979). Ting et al. (2008) found approximately 80 minutes being the limit for safe driving. Mackworth (1969) suggested that performance decreases between the first and second half-hour in vigilance conditions but no significant changes after that are seen. However, there are inconsistencies with this idea. The performance in vigilance task does not necessarily systematically decrease: some studies have indicated that it may also improve or oscillate (Broadbent, 1958). One suggestion is that the performance follows a rhythmic pattern with periodical lapses and re-establishments. Smith, Valentino and Arruda (2003) found different individual cycles in sustained attention performance. It seems that fatigue is contributed more by monotonous environment with repetitive than infrequent stimuli (Thiffault & Bergeron, 2002). In general, time on task (TOT) and monotonous environment have been found to contribute vigilance decrement. In this study, peculiarly long task provides not only a probable vigilance decrement effect, but also an opportunity to detect possible re-establishments in behaviour.

1.3. Reaction time and vigilance performance

Many decisions on traffic are based on the processing of visual information and the drivers need to react quickly to the sudden events they see on the road. RT is the time it takes for an observer to give a response after detecting a target. Visual RT tasks are commonly used in evaluating vigilance performance as fatigue is known to affect activation and thus also RTs (Duffy, 1962). The ability to orient attention and respond to environmental events is extremely reduced during sleep (Posner, Cohen, & Rafal, 1982). Vigilance decrement can be indexed by an increase in the mean RT or by a decline in detection rate of critical targets over time (Parasuraman, 2000). Critical targets are detected slowly if at all when attention has suffered and maybe shifted into irrelevant targets (Kuikka, Pulliainen, & Hänninen, 2001). Both correct and false responses tend to decline over time in vigilance experiments (Dember & Warm, 1979). Egan, Greenberg and Schulman (1961) proposed a signal detection theory to explain this phenomenon: decrement would be due to the observer’s shift towards a more conservative response criterion (Dember & Warm, 1979). In the beginning people may be more inclined for giving responses in general.

RTs are affected also by our overall alertness level and inner homeostatic state. In a research of Graw, Kräuchi, Knoblauch, Wirz-Justice and Cajochen (2004) the slowest RTs appeared when there existed a homeostatic sleep pressure i.e. body needed sleep. Slow RTs and lapses in RT tasks are most probably obtained at late night or very early in the morning. Time of the day affects on performance because of our circadian rhythm; the inner clock controls our general sleep-awake rhythm. Prolonged sleep loss, minimal feedback, monotonous and long task are all contributing the performance decrement (Eysenck, 1982). Normally on road traffic drivers are not purposefully sleep deprived, there is no feedback provided and drivers may be required to drive hours on monotonous environments. These genuine circumstances are replicated in this research. RTs can also be shortened by, for example, providing cues of the location of new target. This prepares the observer as sometimes visual orienting to the right object may require disengaging attention from another one (Parasuraman, 2000). On the other hand, if driver's attention is biased on wrong location, RTs may become longer (Mangun & Buck, 1997). This is an important notice as today many extra devices, like gps, mobile phones and radios, are popular in cars. Anticipation of the stimulus has been indicated to affect also on psychophysiological measures in RT tasks (Lyytinen, 1984). In this research, participants were not able to guess the side or colour of the stimulus allowing SC to reflect connection to actual, unpredictable though not new stimulus.

There may be also more specific reasons for decreased vigilance performance on driving tasks. Vision is perhaps the most important sense of a driver and there are strict laws in Finland how it must function to be allowed to drive. (Ajoneuvohallintokeskus, 2010). Roge et al. (2002) found that the size of visual field deteriorates in monotonous prolonged driving tasks: a phenomenon called tunnel vision effect (Roge, Pebayle, Kiehn & Muzet, 2002). When observers need to react on something occurring either side of their visual field, prolonged task may have narrowed this field and ability to perceive targets has deteriorated shown in poorer stimuli detection. On road this would result in increased accident risk with collaterally approaching objects if environment is observed predominantly from central visual field. Also cognitive workload in a task may lead on poorer detection of peripheral stimuli. Simulator study of Peripheral Detection Task (PDT) revealed that PDT was sensitive on task workloads in the primary driving task (Martens & Winsum, 2000). Subjects were not required to move their head to detect the random visual targets and an accurate response required little conscious attention. Periodically subjects confronted a complex driving situation and the performance in PDT suffered when there was more cognitive workload on driving. PDT performance indicated well the selectivity of attention which seemed to increase with workload. Also along physical exercise RTs have been found to increase to peripheral visual field stimuli while RTs to central visual field were not affected (Ando, Kokubu, Kimuru, Moritani, & Araki, 2007). In this research, vigilance performance is evaluated through a Peripheral Visual Vigilance Task (PVVT) performed concurrently to the driving task. The PVVT could be considered a secondary task though this was not informed to the participants and there should not be any prioritization between tasks. Stimuli appeared on either side of the participant. Narrowing visual field and on the other hand, visual cognitive workload the fatigue driver is exposed would probably at first result in deteriorated performance in PVVT if the selectivity of attention favoured driving task. Though here visual workload is increased by PVVT, it can be considered independent of visually demanding driving task.

The connection between RT task performance and safe driving has been noticed and the applicability of this knowledge on real road traffic been studied. About 15-30 % of fatal car accidents in industrial countries are caused by fatigue but on road police has no tool for testing alertness. Even according to road traffic law driving too fatigue is forbidden. (Liikenne- ja viestintäministeriö, 2005). Knowing that reduced alertness impairs cognitive performance it has been suggested that short cognitive tests could be useful tools for the police. After studying the alertness with standardized tests, police could be able to give advice for drivers or even forbid continuing driving depending on how severely alertness had impaired. Studies from the field have been started and in Finland one remarkable effort is the LINTU project. It is a long term studying and developing programme funded by Ministry of transport and communications Finland, Traffic Agency (Liikennevirasto) and the Safety agency of traffic (Liikenteen turvallisuusvirasto) aiming to reach the kind of road traffic system where nobody has to die or injure severely. In LINTU both road and laboratory settings are used for studying fatigue people's driving ability.

The pilot study of LINTU revealed a simple reaction test being the most effective fatigue indicator compared to for example trail making tests (Liikenne- ja viestintäministeriö, 2005) which require inter alia effective visual search, working memory and executive functions. The reaction test used was psychomotor where drivers were required to give response by pushing the button after detecting a black square on a white screen. RT performance reflected fatigue level: the more drivers had stayed awake, the longer RT was. Considering the amount of sleep, the less drivers had slept, the more they missed targets. Findings suggest that reacting on visual targets is suffering in lowered alertness state. Tasks requiring executive aspect of attention might not be as sensitive to reveal decreased driving performance than tasks requiring sustained attention. One weakness in conducting RT tasks on road is that they require time also from police and shortening tests might reduce their reliability. If applied into road traffic, the test should really be sensitive and specific to detect just fatigue independent of subject's technical abilities. Also, when tests are conducted by police, drivers may be more motivated to perform well than during the actual driving and may also be alerted by even seeing a police. More useful might thus be to develop kind of preventive, alerting device into vehicles to monitor driver's state continuously. As known, there are devices available that prevent the driver to start driving when drunken. One way to monitor driver's fatigue continuously would be to measure the psychophysiological state. The relationship between psychophysiology and driving performance, like RTs, is thus an essential field to study.

1.4. Autonomic nervous system

There are physiological involuntary and unconscious backgrounds for fatigue and arousal processes. Changes in ANS and central nervous system (CNS) activities in vigilance tasks indicate that physiological arousal decreases as there is vigilance decrement or prolonged testing situation (Parasuraman & Davies, 1984). Already Mackworth (1950) suggested that CNS consisting of the brain and spinal cord (Kimble, 1988), and its energetic state are important factors of vigilance (Parasuraman, 2000). ANS is an essential part of alertness controlling for example heart, glands and many autonomous activities which continue also in sleep (Smith, Nolen-Hoeksema, Fredrickson, & Loftus, 2003). ANS regulates processes such as respiration, digestion, heart rate (HR) and has also a major role in emotion (Smith, Nolen-Hoeksema, Fredrickson, & Loftus, 2003). Two divisions of ANS, sympathetic (SNS) and parasympathetic nervous system (PSNS), have different roles in human body and in alertness (Smith, Nolen-Hoeksema, Fredrickson, & Loftus, 2003). Anxiety-producing situations are associated with SNS activity (Kimble, 1988). During intense arousal, SNS's activity gets HR to become more intense, perspiration, muscle potential levels and SC to increase and the arteries of the skin to become constricted (Andreassi, 2007; Smith, Nolen-Hoeksema, Fredrickson, & Loftus, 2003). Additionally, it activates certain endocrine glands which increase arousal. The reticular formation, a network of neurons regulating important primitive behaviours necessary for survival, has also been found to control arousal and have a role in focusing attention. (Smith, Nolen-Hoeksema, Fredrickson, & Loftus, 2003). The PSNS is associated with rest for example by slowing the HR (Andreassi 2007; Smith, Nolen-Hoeksema, Fredrickson, & Loftus, 2003).

An essential role of the ANS while driving a car is to keep the body ready for action when needed. Preparing the body and its' resources for future's action is an important dimension of diverse functions of the ANS (Lyytinen, 1984). For example in addition to cooling, the function of respiration is adaptive also because it contributes bodily efficiency in emergency situations (Andreassi, 2007). Sweat gland activity can be seen as changes in SC by increasing it with higher levels of arousal and decreasing at low levels (Andreassi, 2007). Alertness variability on road traffic can be explained via ANS processes. An arousing event, such as an unexpected stimulus, activates SNS from reduced alertness condition when PSNS was in dominance.

1.5. Arousal

Arousal, also described as a waking up of the brain (Kolb & Whishaw, 2003) is an essential part of alertness. According to Duffy (1962), arousal or activation refers to variations in the excitation of individual as a whole. Duffy (1962) points out that the level of activation could be defined as the extent of release the potential energy stored in an organism. Arousal is joined by multiple psychological and physiological reactions and can be reflected inter alia in SC (Duffy, 1962). Eysenck (1982) supports the idea that there are probably many arousing agents, including also dimensions such as stimulant drugs and ego threat, rather than just a single elicitor.

High arousal has many common components with phenomenon called orientation reaction (OR). Both states are accompanied with manifestation of sympathetic dominance (Kahneman, 1973). Novel and significant stimuli are eliciting a pattern of physiological responses, OR (Kahneman, 1973). The purpose of physiological changes in OR is to make an organism more sensitive to incoming stimuli and its body more equipped for needed action (Lynn, 1966). Similarly arousal response can be produced by new, unexpected and stimuli that are difficult to interpret and capture attention (Mackworth, 1969). Furthermore, if something unpredictable occurs on the road, it probably produces arousal and automatically captures the driver's attention. Habituation on environmental, repetitive stimuli is natural but also a threat in driving: along habituation, the function of ANS is changing affecting also on alertness. In this research, participants practice driving and responding on light flashes before the experiment, so they are habituated on stimuli and thus are required purposefully to orient attention towards targets.

As attentional processes inevitably are present in arousal, it has been linked also with sustained attention performance. Arousal or activation theory is one attempt to explain vigilance neurophysiologically (Dember & Warm, 1972).The relationship between vigilance and arousal is especially interesting from the viewpoint of prolonged car driving. Earlier studies suggest arousal having much to do with the overall level of vigilance but that it is not so directly connected with vigilance decrement (Parasuraman, 2000). Factors increasing observer's arousal level seem to increase the overall vigilance level, but reduction in cortical arousal is not the only explanation for vigilance decrement. Contributing vigilance performance through arousal on road traffic has been studied. Setting certain visual stimulation on roadsides could be useful for arousal by interrupting the monotony of the environment (Thiffault & Bergeron, 2002). Driver is dependent on vision and visual input would thus be an effective way to produce arousal. Sensory input is yet not the only factor affecting periods of sleep and wakefulness: mid-brain has its own mechanisms for this and even without sensory input there are many pathways in hypothalamus influencing arousal. (Kalat, 2007).

Important source of arousal is suggested to be also someway psychological: sensory information and stored experiences are combined to form the stimulation together (Lyytinen, 1984). Specific sensory input would not probably produce the same reaction without driver's earlier knowledge about for example the danger related to the perceived stimulus. Interesting is whether sensory information arouse drivers equally on different alertness levels. Lowered arousal in vigilance tasks can be indicated by many different physiological signs (Parasuraman & Davies, 1984). According to Parasuraman and Davies (1984) typically in lowered arousal states SC and mean HR decreases and HR variability increases. SC, EEG and HR are common measures of arousal though they have been found not to correlate with each other very strongly and may even act contradictory among each other (Eysenck, 1982). A reliable psychophysiological measure of arousal, SC, provides a way to explore arousal as it is controlled by ANS and thus cannot easily be consciously manipulated. In this research, one point of interest is to see how autonomic SC reacts also in situations when drivers do not give responses: the brain may still perceive visual stimulus and react on it in a manner the observers set their detection goals in the beginning. Easily perceivable stimulus may arouse the brain though drivers' alertness has reduced so that they are unable to react as fast as should, indicated by RTs. SC normally can not be under active monitoring of a driver and can thus be used either a precursor or indicator of reduced capability to drive safely.

1.6. Autonomic responses and skin conductance

According to Kahneman (1973), different stressors evoke different patterns of autonomic activity. Arousal level has traditionally been tried to identify through nervous system variations including SC variability (Kahneman, 1973). It is one of the most commonly used psychophysiological measures of vigilance, partly because of its sensitivity on arousing events (Eysenck, 1982). SC response (SCR) tells indirectly about the ANS activity (Laine, Spitler, Mosher, & Gothard, 2009) and is maybe the most widely used ANS measure (Lim et al., 1996). Measuring electrical activity of the skin is a substantial part of psychophysiological research and changes in electrodermal activity (EDA) have been found to occur with many kinds of sensory, psychological, attentive and emotional stimulation (Andreassi, 2007; Laine, Spitler, Mosher, & Gothard, 2009). Tonic level refers to relatively stable EDA whereas phasic responses refer to momentary fluctuations in it (Andreassi, 2007). Higher sweat level in the gland increases the conductance.

Alertness and arousal are reflected in EDA which makes SC a sensitive indicator of physiological changes in human performing different kinds of tasks. In a study of Collet, Petit, Priez and Dittmar (2004) participants drove a demanding situation trying to avoid an obstacle. In addition to SC measuring, participants performed a cognitive Stroop test before experiment. Findings revealed that participants with highest SC arousal were able to avoid crash. Participants who performed the worst in obstacle avoiding performed worst also on Stroop. This suggests that SC could be used in evaluating ability to manage demanding driving situations as high SC arousal was connected with good driving performance and ability to act fast. Furthermore, autonomic SC, cognitive performance and driving behaviour seemed to be connected. Interesting is if driving performance, alertness and SC are connected also in prolonged situations where ANS activity tends to decline.

Arousal and adequate alertness are critical for driver's ability to react in a safe manner on road. In Blakeslee's (1979) studies observers needed to detect certain stimuli from quite similar ones during two 30 min tasks. SCR magnitudes were larger both before and after detected signals compared to misses, suggesting that presignal orientation reactions may be critical for successful performance. SCR magnitudes declined over time in both before and after signal presentation time epochs. Habituation of the orienting reflex to signals was associated with changes in vigilance performance over time (Blakeslee, 1979). Because there were larger SCR magnitudes also after misses, it seems that motor activity is not the only factor of the intensified SCRs after detections. Findings supported the idea that also mere stimulus registration can be indexed through SCRs; observers with SCRs may be consciously or not aware of ignoring possible events. In this research, the interest is to examine a longer and a bit simpler setting. Observers need to react each time there is a stimulus presented and the discrimination has to be made only between red and green lights. Stimuli are nearly impossible to be unperceived unless participant is asleep, helping to ensure that missed signals are either consciously ignored or the observer is doing something irrelevant related to the task. Also here detection requires motor activity but as indicated, there might be enhanced SCRs also after misses (Blakeslee, 1979). In this research participants perform approximately three-hour monotonous task which is fairly long even in the general field of vigilance research. Here the supposition is that long task will decrease also the ANS activity in general more probably.

Drivers seem to be less vulnerable on drowsiness when driving in a city centre or when having someone to talk to as drivers are somehow mentally activated. SC reflects not only physiological but also psychological processes of a human revealing something of multiple psychophysiological events in us. Naccaches et al. (2005) found a tight relation between SCR variations and conscious mental effort. Kahneman (1973) suggested that high arousal may reflect what subjects are doing and the effort they are investing or it may reflect what is happening to the subjects and the stress they are exposed. Kahneman proposed that mental effort in a task may have physiological arousing effects i.e. the task performance affects on arousal while usually researchers concentrate on the effects of arousal on performance. According to Kahneman (1973), arousal and effort are not usually determined prior to action but they vary continuously depending on what one is doing. Effort and mental activity have been found to be useful in keeping the driver alert: in Verwey and Zaidels's (1999) simulator study, drivers who used kind of gamebox during drive, reported less drowsiness, were less exposed to accidents or these occurred later and overall had less periods of sleep than controls. Driving performance deteriorated progressively but less in the group using mentally activating gamebox. Mental activation thus kept the physiological alertness up.

In Helander's (1978) research, time sequence analyses indicated that mental effort was reflected in EDA data, supporting the idea that motor or physiological factor is not required for producing SCR. The difficulty of the task and mental effort related to it themselves were sufficient for producing SCR independent of motor activity. Furthermore, physiological measures have been found to vary with task relevance: Barcelo, Hall & Gate (1995) found that higher task relevance and higher workload increased SC orientation reaction. SC has also been found to vary with emotional relevance of a stimulus to the observer. Codispoti and De Cesarei (2007) found that emotional modulation of SC increased linearly with larger picture sizes possibly because of higher arousal to larger stimuli. Suggestion is that emotionally irrelevant stimuli would not produce as high SCRs as relevant ones. It could be assumed that people react individually on different kinds of stimuli: there could be variations in ANS and thus in SC reactions. However, there are contradictory findings. Some suggest that endogenous factors affect on performance (Eysenck, 1982; Thiffault & Bergeron, 2002). But for example, Mardaga's et al (2006) found no differences between personality dimensions in SCR magnitudes on emotional pictures though differences occurred on response duration. This finding is among those encouraging studying arousal and vigilance performance as a general phenomenon, without specifying individual personality characteristics and considering SC independent of personality traits. It could be assumed that this is even more reliable with emotionally neutral stimuli, like in this research.

Individuals may take different kinds of attitudes on test situations which may affect on task performance. Psychophysiological measures can be used to support behavioural findings as they provide kind of deeper insight into studied phenomenon. Ward, Brickley, Sharry, McDarby & Heneghan (2004) explored the relationship of Sustained Attention to Response test (SART) on EDA and HR variability. Participants were classified into two groups according to the error rate, including both omission and commission types of errors. Participants with less than 15 % of total error rate formed one group and those greater than 15 % of total error rate the other group. The mean SCR during no-go trials differed significantly between groups: the lower total error rate group had significantly greater SCRs for no-go trials compared to the group of higher total error rate. In lower total error group participants showed greater SCR levels also during errors though no significant difference was found. However, the size of samples was small and there were problems in pairing the certain SCR to a specific stimulus. Findings still suggest that persons with stronger emotional responses during no-go trials and errors may make fewer errors.

1.7. Applications of electrodermal activity measures in the transport industry

As EDA is considered being a reliable measure of alertness state, there are considerations of using it in car industry. Clarion et al. (2009) describe an integrated device to evaluate driver's functional state. The device measures many psychophysiological activities, including EDA, as an aim to reveal driver's state while driving. In Australia, some vigilance technologies have already been adopted on railway traffic (Dorrian, Lamond, Kozuchowski, & Dawson, 2008). One of the promising recently developed and now studied kind of a monitoring device is called Driver Vigilance Telemetric Control System (DVTCS) and which is based on measuring SC variations. It monitors the driver's alertness state during sustained attention performance (Neurocom, 2009). Continuous psychophysiological measuring recognizes driver's state's variations from alertness to relaxation and warns the driver with an alarm when threatening lowered alertness state is near. Driver must press a button to shut off the alarm which in turn resets the device and starts the calculation from the beginning. DVTCS takes into account the so called critical vigilance level in which a person is still able to operate though with lot more mistakes. DVTCS consists of a ring and/or wrist components the driver wears while driving. (Neurocom, 2009; Dorrian, Lamond, Kozuchowski, & Dawson, 2008). A bit broader version of this, Engine Driver Vigilance Telemetric Control System (EDVTCS) is already adopted into railways on some areas.

DVTCS has gained interest worldwide though there are controversial results of its' practicality (Dorrian, Lamond, Kozuchowski, & Dawson, 2008). DVTCS measures the level of vigilance through EDA. In the research of Dorrian et als (2008) the function of DVTCS was investigated. Device was genuine with the only difference that participants were blind to their own vigilance level as it was the researcher who reset the device in another room instead of drivers themselves. Participants performed also psychomotor vigilance task (PVT) while driving. RTs increased significantly during the experiment, that is, during the imposed period of keeping awake. Contrary to performance in PVT, DVTCS indicators did not vary significantly during the task. Findings suggest that this kind of EDA indicator might not be enough sensitive in all levels of fatigue. More investigations are thus needed about the relationship between SC and RT performance.

1.8. Factors influencing vigilance performance

There are many dimensions worth considering when evaluating human behaviour in vigilance conditions. Observer's performance is dependent not only on perceptual but also on decision factors (Parasuraman, 2000). The latter include observer's detection goals, expected consequences of correct and incorrect responses and expectations about the nature of the stimuli. Dember and Warm (1979) suggested that factors behind the vigilance performance could be classified into first-order sensory factors where physical property is somehow manipulated and second-order factors affecting after observer has gotten some experience of the task, including the uncertainty about when and where the signal is going to appear (Dember & Warm, 1979). It can also be considered whether the vigilance decrement is due to a loss in sensitivity to signals or alternatively observer has adopted a stricter response criterion (Eysenck, 1982). Also feedback has its' effects: in RT tasks with no feedback provided, RTs may increase even right after the first 5 minutes and soon after that recover to the normal level (Mackworth, 1969). Motivation is yet an important factor to consider in vigilance performance. Eysenck (1982) points out that information processing and cognition are both affected by motivational and emotional factors and increased arousal improves attention According to Yerkes and Dodson (1908) performance is the best when motivation is at a moderate level and suffers if motivation is either very low or very high and that in easy tasks motivation or arousal is higher in comparison to difficult ones (Eysenck, 1982). On the other hand, new experiments have indicated that RTs are faster with higher SC level, that is, with higher arousal (Andreassi, 2007). On individual level, drug intake, nutrition and exercise are also among important factors known to affect on activation and thus on RTs (Duffy, 1962).

Individual differences may occur in ways people perform in monotonous tasks (Mackworth, 1969). A risk of testing too similar people with each other exists in small samples. One proposition is that introversive people are generally more aroused than extraverts (Eysenck, 1982). Differences between sexes have also been investigated. Giambra and Quilter (1989) found women to be slower in responding, respond to fewer targets and to be less aroused than men in RT tasks. In Mardagas et al (2006) study women showed larger SCRs and longer half-recovery times compared to men to negative stimuli. In a research conducted on military truck drivers emerged differences between particular groups how subjects performed in driving task (Oron-Gilad & Shinar, 2001). Younger, less experienced drivers lower in military ranks were the most probable to fall asleep. Furthermore, this group was sensitive to sleep deficits and more influenced by external events like boredom. In the same research was also found that it is not enough to force drivers to sleep before allowing them to go on driving; the good quality of sleep should also be ensured. Also some illnesses may have their effects on physiological responses. Study of Pazderka-Robinson, Morrison and Flor-Henry (2004) indicated that people with chronic fatigue showed lower prestimulus tonic SC levels than controls or depressive people.

1.9. The importance of this research

Finland's Central Organization for Traffic Safety (Liikenneturva) stresses that, in the first decade of 21st century, the percentage of fatal passenger car accidents is about 60 % of all road traffic accidents while in the 1980's it was 37% (Liikenneturva, 2008). According to Central Organization for Traffic Safety, as much as 75% of the fatal passenger car accident types are running off the road and encountering of the cars with opposite directions without turning, that is, head-on collisions. These accident types are probably often caused by inattention, in a way or another: driving a car is a natural example of vigilance task. As much as 90% of fatal and 60% of injuring passenger car accidents take place outside the population centre and one of the major risk factors for accidents is the driver's fatigue (Liikenneturva, 2008). Reduced alertness is undeniably a bigger risk outside the population centre because of slight stimulation. This may lead to inattention and the driver is less able to consider the situational factors in driving.

This research was done under vigilance task conditions. Earlier studies have indicated that RTs typically increase in monotonous tasks. Findings have revealed also that the function of ANS tends to be balanced by PNSN by for example decreasing the SC in vigilance conditions. The hypothesis was that the task indicates possible vigilance decrement over time through changes in RTs and SC. In order to test the hypotheses a within subject design was used in which participants' performance in RT task and SC measures were analysed. Drowsiness may easily lead to inattention and longer eye blinks or even sleep, causing a serious threat for safe driving and accurate reactions. Cases of false responses and misses are thus taken into account here, including also SC examinations. This enables us to see, whether the brain registers stimuli though driver does not objectively react. It is essential to study human performance as a whole, concerning both the physiological and behavioural aspect as both are present in everything human does and are affecting to the outcome. Together the behavioural and autonomic measures are hypothesized to provide a broader insight into vigilance performance and to detect driver's fatigue more reliably than one measure by itself. Finding connection between these variables could provide help for future's car industry in developing vigilance technology applications on road traffic. The connection between autonomic SC and voluntary RT are hypothesized to reveal more of the vigilance decrement than either aspect alone and could possibly be used in future's car industry.

1.9.1. Research questions

1) How reaction times (RT) change during the long and monotonous driving task?

2) Is there a connection between RT and skin conductance (SC) amplitude and frequency?

3) How SC behaves when reacting on visual stimuli:

   a) in normal RTs

   b) in long and short RTs?

4) How SC behaves in situations when the driver

   a) does not give a response in appropriate time, i.e. misses a stimulus?

   b) Misclassifies a stimulus, i.e. responds green when the light is red and vice versa?

2. Method

2.2. Participants

Participants were volunteer students from local school. There were 17 adult students, 16 men and 1 female aged from 20 to 45 (*Mean* 30.7). All were studying professional truck driving aiming to have C/D (bus/truck) driving licence and already having B-driving license. Everyone drove weekly and in all 5000-25000 km in year. Subjects were right-handed and had normal or corrected-to normal vision. They were non sleep deprived to get as reliable and common daily-life situation as possible. Subjects were contacted via their school and each got one credit in their studies by attending this research. Otherwise no rewards were given. Subjects were tested in 2007-2008. Research ethics was taken into account and the anonymity of the subject was guaranteed. Sample represented particularly the profession group which will very probably be challenged by fatigue while driving on the road in their future daily work.

2.1. Instruments and materials

This study was part of the research project *Monitoring driver's alertness in a simulator*. The aim of the entire project was to examine different psychophysiological and psychological variables during a long and monotonous task performed in an established driving simulator. In this research, the interest was to investigate the effect of fatigue on vigilance performance through two measures: reaction time (RT) and autonomic skin conductance (SC). Research was conducted at the University of Jyväskylä, Agora Center. The driving simulator was planned collaboratively by JYU and Neuroarviot Oy and it was constructed on personal computer (PC) for Windows XP. Simulator contained a Logitech MOMO Force throttle and brake pedals, and steering wheel. The feedback property of the steering wheel was turned off because of electrodermal activity (EDA) measurement. The driving environment was back projected on a screen size of 1080 x 924 mm located 1250mm from the driver seat. Driving task was very simple and monotonous: no other traffic was presented in the road environment. The road was 8000 m long, mainly straight with regular turns on left because of the oval shape of closed track. During a round there were two 2574 m long curves with 820 m radius and 28 degree banks. Environment was extremely non-stimulating. All the time there was a wall on right side of the lane and grass area on left. Participants were able to regulate their speed and it was also possible to drive off the road. Driving off the road did not end the experiment but the participant was able to continue driving right away. There was a speedometer, but not an odometer nor a clock.

The behavioural task performed in parallel with the driving task was a peripheral visual vigilance task (PVVT) which was the particular interest of this research. PVVT, containing the visual choice reaction time (RT) task, was performed right from the beginning of the driving task to the end of it. This meant maximum 180 minutes driving and responding for each participant. PVVT was on a different PC and commanded by E-Prime Software (Version 1.1, Psychology Software Tools, 2002). It controlled two LED lights, red and green, on both collateral sides of the screen, 20 degrees from the participant and each of the four diodes was 2 cm in diameter. Drivers were instructed to give a response every time there was light flashing as soon as possible by pushing corresponding red or green button on a steering wheel with the right thumb finger. Response turned off the light. There was 2000 ms time to respond before E-Prime automatically turned off the light and recorded it as a miss. The transistor-transistor logic (TTL) pulses indicating the light presentation and response and turning on the light and receiving responses was done through parallel port. The TTL pulses were recorded by DSAMP. The PVVT data was recorded on one channel of physiological data acquisition system to guarantee the concurrency between EDA and PVVT. (Gonzalez, Kalyakin, & Lyytinen, submitted in 2009). Light flashes were presented on either the left or right periphery of the visual field above the dashboard. Light flashed in randomized inter-stimulus-intervals, colours and sides making it impossible for the participant to learn when and which of the lights would flash next. The aim was to investigate how RTs change during the task.

Autonomic physiological measure of this research was SC and it was examined in parallel with the PVVT. The aim was to see how SC reactions are related to performance in PVVT. The interest was to explore if SC behaved differently when RTs were short compared to long ones and, in addition, how SC behaves when drivers miss or misclassify stimuli. The EDA data was acquired with a custom designed GSR recording device. This device was designed by Carl Hagfors at the University of Jyväskylä about 1970 for his doctoral thesis. The data were collected using D-samp program. The unit of measurement of the skin conductance was microsiemen (µS) which was acquired through a calibration device. Electrodes used here were disposable Ag/AgCl Neuroline 72501-K electrodes with 7 mm inner diameter. The electrodes were filled with ElectroGel and placed on the palmar side of middle phalanx of the index and anular fingers of the non-dominant (left) hand. The constant voltage was 1,000 V. The 10 µS change input corresponded to 2,5 V change in output. The A/D board was bit DAS –PHG, Lab Master DMA, Input Range +/- 10,0 V. The final curve of conductance behaviour consists of the basic (tonic) level of SC and responses to stimuli (phasic) (Lyytinen, 1973). This change between the basic level and a response indicated a SCR. Also magnitudes of SCRs were measured. This was obtained through examining properly the level just before stimulus presentation (Lyytinen, 1973). The SCRs were scored based on the change between prestimulus and peak amplitude levels during a trial i.e. stimulus presentation. In this research, a method similar to the one used by Codispoti's and De Cesarei's research (2007), was used. The average of 1 second before stimulus onset was used which made it possible to compute a change score for the following 3 - 4 seconds. After this the amplitudes of these SC activities were calculated. This is a typical method for this kind of analysis. It has been noted that the peak in SC amplitude change occurs 0.5 - 4 seconds after stimulus presentation (Lyytinen, 1973).

Participants wore headphones during the experiment because of MMN examination. This included presentation of infrequent, insignificant voices. Other voices, like traffic noise, were not presented but there was a silence in the experiment room. Meanwhile performing the task, multiple psychophysiological, psychological and behavioural variables including RT, EDA, electroencephalograpic (EEG), blink rate (BR) and heart rate (HR), were measured. Also speed variability, activity on the throttle and steering wheel behaviour were measured. Two videocameras recorded the performance of each driver, one from the back and other from diagonally front. Results of EDA and PVVT data are presented here. Other findings, including also PVVT data, are reported in the article of Gonzalez, Kalyakin and Lyytinen (submitted in 2009).

2.3. Procedure

Subjects arrived in Agora Center about at 11 am and had lunch in the same building before starting the experiment. After arriving at the laboratory, different questionnaires were filled and the participants were informed about the nature and duration of the task, which was approximately three hours. Subjects signed an informed consent before starting the experiment. After that the electrodes for EDA, EEG, BR and HR measuring were attached on the participants. The experiment was ready to begin at 13-14.00 which meant driving also during a so called early afternoon dip when alertness and good driving performance are especially susceptible to decrease

(Lenne, Triggs and Redman, 1998). Participants performed the task alone. After seating at the wheel of the simulator, each participant set the seat as it was suitable for them. Participants were allowed to practice driving in a simulator for approximately 15 minutes to become familiar with the equipment before starting the experiment. Instructions were given to keep their speed at constant 120 km/h, and aim to drive on the centre of the lane, avoid strong manoeuvres and to respond to the lights as soon as possible. Subjects were also asked to ignore the sounds from headphones and to restrict left hand’s movements in order to reduce movement artifacts. Participants were encouraged to keep on driving even if they felt sleepy. Once started, the task was performed without pauses and without any communication between the experimenter and the subject. The experimenter told when the task was finished if the participant did not absolutely want to stop earlier. Subjects were not aware of the task progression nor were they allowed to wear watches during the experiment. With long duration of the task the performance degradation and lowered alertness state were more probable to achieve.

2.4. Analyses of reaction time

Statistical procedures were performed with SPSS 13,0, 15,0 and 16,0 for Windows program. Also Microsoft Excel was used for some calculations. Data were in excel-tables.

The first aim was to see if there were changes in RTs during the task. Each participant's trials were blocked into groups to ease the analysing process. Blocks represented time on task (TOT). Within each participant, 36 trials were included in each block starting from the beginning of the experiment and continuing to the end of it. Each block was duration of approximately 9 minutes. Because one of the participants wanted to stop the task after completing 16 blocks, no more than 16 first blocks (i.e.144 minutes) of all participants’ performance were included into analysis. Other subjects completed 17 to 22 blocks. Missing values in RT blocks were replaced with linear interpolation function to get a more reliable result of RT changes. Means and standard deviations of the blocks of trials were calculated in each participant separately. After that combined means of blocks were calculated to find out average RT behaviour in 17 participants. Tests of normality and Spearman correlations were explored. Linear regression analysis and curve fit were analysed.

RTs were classified into five equally distributed quintiles (qnt). Quintiles 1-5 each contained 20 % of correct responses and were constructed on the basis of the latency of each participant's individual RTs so that quintile 1 comprised the shortest and quintile 5 the longest RTs. In addition two exterior groups were constructed on the basis of quality of RT. Group number 0 was for cases when participant did not give a response though stimulus was presented, in other words misses. Group number 9 included misclassifications, i.e. the participant responded red when the light was green and vice verca. Quintiles were calculated individually for each participant so that each quintile included 20 % of that specific participant's RTs. As a result for instance some participant's longest RT in quintile 1 might be as long as some other participant's relatively short RT in quintile 2. Standard deviations between quintiles were analysed with within-subjects function corrected by Huynh-Feldt method.

2.5. Skin conductance analysis

SC amplitude and SC latency were recorded from each participant. The EDA data was synchronised with PVVT data so that it was possible to explore the relationship between these variables. In this research the target of interest was SC amplitude which tells about the average of peak SC responses in different PVVT responses. At first cross-tabulation between RT quintiles and SC amplitude was made. Within-subjects comparisons were used for exploring the differences of SC in different RT quintiles. As the classifications of RTs into quintiles formed the basis of analysing process, RT quintile was the independent variable and the behaviour of dependent SC was explored in relation to it. Within-subjects model was corrected by the Huynh-Feldt method for violations of the sphericity assumption. Also Spearman correlation coefficient was explored. After this SC amplitude was examined more carefully revealing that not each of the visual stimuli presentations (= trial) evoked an arousal according to SC amplitude. There were also negative values among SC amplitudes, suggesting that there was no arousal reaction on some of the trials. The original interest was to see whether there were differences between RT quintiles in SC amplitudes. The most informative related to this was to take all the trials with positive SC values and consider these as SCRs, reflecting arousal responses in general. The SC amplitudes were classified into two classes, class number 1 (= a positive SCR) and 0 (= non-SCR). The latter contained the cases when SC amplitude was max. 0,000. This way it was possible to count the whole number of trials and the sum of the trials with positive value**.** If there was a positive value, the trial evoked a SCR and thus an arousal response and vice versa.

The interest was to see if SCRs were more frequent in some RT quintiles than in others giving direction if there were relatively more arousal reactions in shorter or longer RT quintiles or perhaps in misses or false responses. The percentages of how many of trials in different quintiles evoked a positive SCR was calculated from each participant separately and then from all 17 participants. The bar graph was drawn to see if there was a visible difference in SCR percentages between RT quintiles. After this all trials with positive SC amplitudes, in other words SCRs, were examined more accurately. Within-subjects model corrected by Huynh-Feldt method was used for SC analysis. The interest was to find out the means of positive SC amplitudes in different quintiles and to explore if there were statistically significant differences in magnitudes between quintiles. Also the differences of SCR frequencies between quintiles were tested through within-subjects model.

3. Results

3.1. Reaction time

In reaction time (RT) data the interest focused on average behaviour of 17 subjects. Hypothesis was that RTs increase along the time on task (TOT). Altogether 16 blocks, including 144 first minutes of each participant's task performance, represented TOT. Linear regression model indicated that RTs increased linearly over time. Linear regression curve explained as much as 72, 8 % of RT variability. Linear regression model fit into the sample in a statistically significant manner as the p-value was 0.000. Block number had a significant effect on RTs as also here the p-value was 0.000. (see Figure 1). In other words time on task (TOT) predicted RT. Mean RTs of blocks followed normality plots as the p-value in Saphiro-Wilk test of normality was 0.611. This means that the frequency of RTs of average latency was greater than the frequency of relatively short or long RTs. Spearman correlation analysis revealed a strong correlation between these variables (0.824**) which was statistically significant at the 0.01 level and p-value was 0.000. Hypothesis that RTs increase as the time goes, got support.

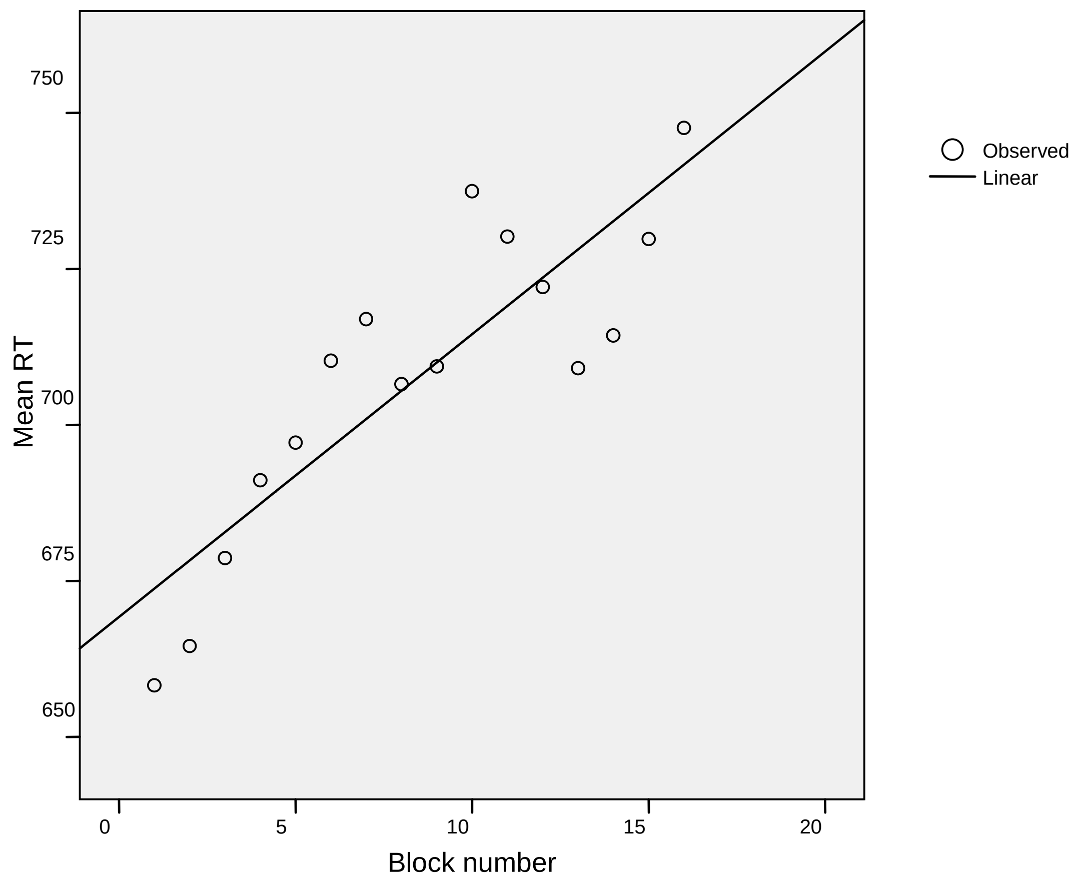

Figure 1. Linear regression model of reaction times (RT) and time on task (block number).

RTs were classified into quintiles (qnt) 1-5 according to the latency of RT. In addition to these, two exterior groups, 0 and 9, were formed to include misses and misclassifications. Means and standard deviations of quintiles 1-5 were calculated. In order, means for RT quintiles 1-5 were 525.81, 610.01, 673.43, 743.17 and 988.04 (*SD*s = 44.48, 20.09, 21.42, 30.99 and 198.50, respectively). It is worth of noticing that standard deviation of quintile 5 was clearly the greatest and differed significantly from quintiles 1-4. Also the standard deviation of quintile 1 was relatively great compared to quintiles 2, 3 and 4.

3.2. Skin conductance

The interest was to see if there were statistically significant differences in arousal responses between RT quintiles. Repeated measures ANOVA was used for exploring the differences within SC between quintiles 1-5. Interest was to explore how dependent SC was related to independent variable RT quintile. Hypothesis was that RT and SC are connected with each other so that the length of RT is reflected in autonomous SC. As shown in table 1, within subjects ANOVA corrected by the Huynh-Feldt method (Epsilon value in Muachly's test of Sphericity .670) indicated that SC amplitudes differed significantly from each other in different RT quintiles.

Spearman's rho Correlation coefficient revealed a statistically significant connection between RT quintile and SC amplitude: the correlation between quintile (1-5) and means of SC amplitudes was as much as 1,00. (significant at the 0.01 level, two-tailed).

Table 1

Within subjects analysis of skin conductance (SC) amplitudes in quintiles 1-5. Tests of Within-Subjects Contrasts.

Quintile contrasts	*df*	*F*	*MSE*	*p*
qnt 1 vs. qnt 5	1, 16	12.96	5.04	.002
qnt 2 vs. qnt 5	1, 16	10.66	4.27	.005
qnt 3 vs. qnt 5	1, 16	10.84	3.30	.005
qnt 4 vs. qnt 5	1, 16	11.55	3.15	.004

Note. *qnt*, quintile. Quintiles 1-5 each contained 20 % of RTs (qnt 1 the shortest and qnt 5 the longest 20 %); *df*, degrees of freedom; *F, F*-ratio; *MSE,* mean square error; *p,* significance level.

Because in some trials there were negative values among SC amplitudes, the arousal component was taken under a more précis examination. Positive SC amplitudes were considered as SC responses (SCR) and these represented arousal reaction in general. Reaction time quintiles 1-5 represented the delay of starting to act while groups 0 and 9 represented kind of fail in the task. The classification of the latency and quality of RTs was the basis of this analysing process and SCRs were studied in each different quintile from each of the 17 participants. As shown in figure 2, when examining only quintiles 1-5, bar-graph suggested that there were greatest frequencies of SCRs in quintile 5 with longest RTs. Quintile 1 evoked the second greatest frequency of SCRs within quintiles 1-5. Quintiles 2, 3 and 4 seemed to evoke approximately equal frequencies of SCRs. Also quintiles 0 and 9 are represented in figure 2 to ease the comparisons. Bar-graph revealed that there seemed to be the greatest frequencies of arousal responses in RT groups 0 and 9 (misses and misclassifications), that is, in groups different from actual quintiles. RT quintiles and groups thus were connected with SCR frequency in this research, though not in an obvious manner.

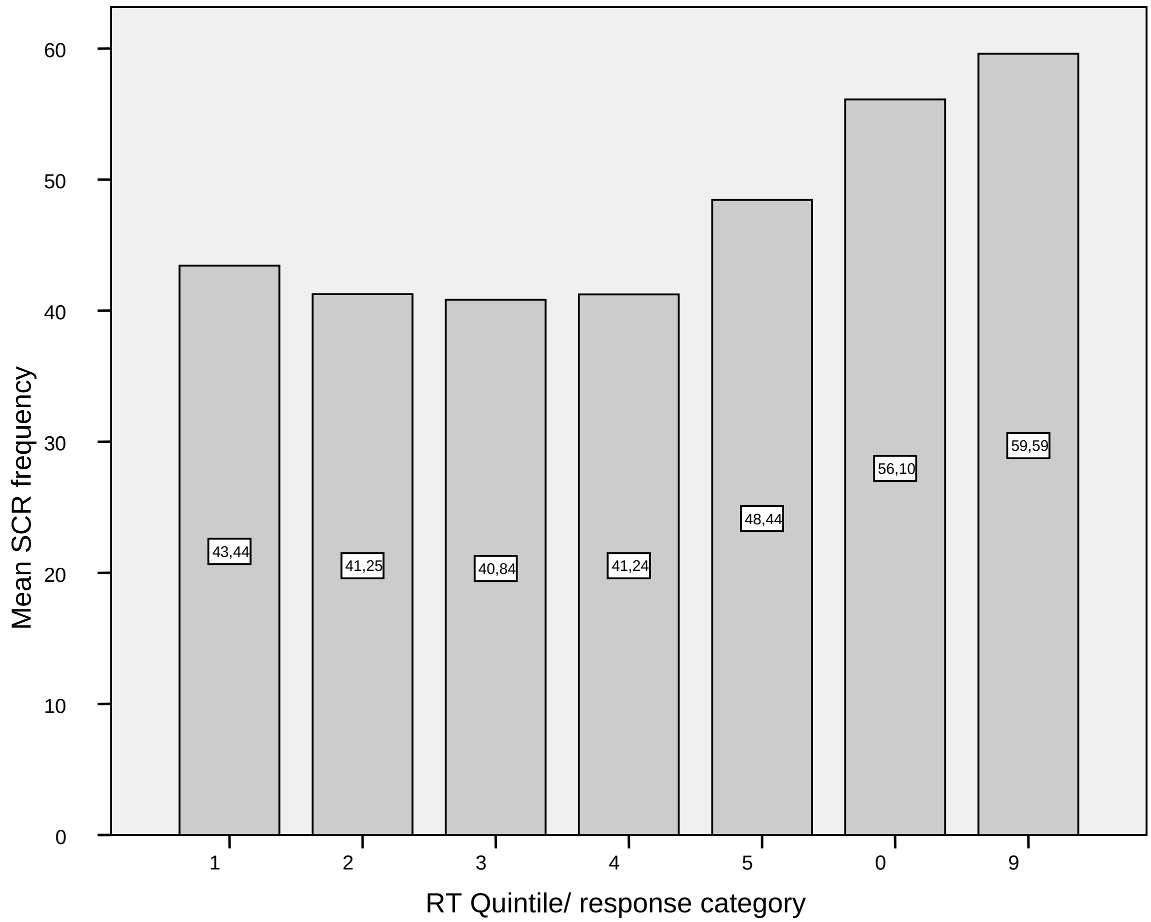

Figure 2. Frequency of skin conductance responses (SCR) in each reaction time quintile (RT Quintiles 1, 2, 3, 4, 5), and response categories (0 = miss, 9 = misclassification).

SC amplitudes of positive SCRs were examined next. Within subjects model corrected by Huynh-Feldt method (Epsilon value .957) was used for exploring whether the differences of SC amplitudes in positive SCRs were statistically significant between quintiles 1-5. In this case, groups 0 and 9 were not included because of their different nature. As shown in table 2, quintiles 3 and 5 differed significantly from quintile 1 in case of SCR amplitude means. Surprisingly quintile 4 did not differ from quintile 1. However, progressively greater amplitudes of SCRs were showed in longer RT quintiles in general. The frequency of SCRs did not explain the case of quintile 4, in which the mean of SCRs was near of the mean in quintile 1. It must be reminded here that when SC amplitudes of each trial, including also negative values, were taken into analyses, means of SC amplitudes did differ significantly between quintiles. There was also a significant correlation between quintile and SC amplitude. Anyhow, also among only positive SCRs, in general the longest RTs still were associated with greater SC amplitudes compared to RTs belonging to smaller quintiles.

Table 2

Within subjects analysis of mean skin conductance (SC) amplitudes of positive SC responses (SCR) between quintiles. Tests of Within-Subjects Contrasts.

Quintile contrasts	*df*	*F*	*MSE*	*p*
qnt 2 vs. qnt 1	1, 16	0.72	.19	.408
qnt 3 vs. qnt 1	1, 16	5.41	1.28	.033
qnt 4 vs. qnt 1	1, 16	0.04	.01	.830
qnt 5 vs. qnt 1	1, 16	6.63	3.95	.020

Note. *qnt*, quintile. Quintiles 1-5 each contained 20 % of RTs (qnt 1 the shortest and qnt 5 the longest 20 %); *df*, degrees of freedom; *F*, *F*-ratios; *MSE,* mean square error; *p*, significance level.

The hypothesis that the latency and quality of RTs are reflected in autonomic SC obtained support. RTs and SC were connected in this research though not completely straightforwardly.

4. Discussion

4.1. General

The aim of this research was to study fatigue while driving through a vigilance task. Participants drove 144 minutes in a monotonous environment performing a PVVT in parallel. Light flashes of PVVT provided the only deviant stimuli during the task. Reaction times (RT) and autonomic skin conductance (SC) measures were recorded continuously from each participant (n=17). These two variables represented the voluntary conscious response (RT) and autonomic response (SC). Via well-established variables it was possible to easily and reliably measure vigilance performance during a long and monotonous driving task performed in a carefully planned driving simulator task. Participants showed no prioritisation of PVVT nor the driving task, as instructed. It can thus be assumed that participants gave an equal importance and effort for both tasks.

4.2. Reaction times

Participants needed to capture the deviant events from the basic driving environment. This meant capturing unrelated light flashes while performing a monotonous driving task. In general, participants showed RTs of different latency during the experiment. Formed RT quintiles 1-5 each contained 20 % of correct responses. Standard deviations (*SD*) were the greatest in quintile 5 including the longest RTs. As RTs started to be longer, they were more scattered in time. Also *SD* of quintile 1, comprising the shortest RTs, was relatively great compared to quintiles 2, 3 and 4. The shortest 20 % of RTs were still clearly closer to each other than the longest 20 %. It seems that participants thus were motivated to give responses fast in general as RTs were emphasized on smaller quintiles. This is an important note as motivation is known to have great effects on performance and this way also on analyses of vigilance tasks (Eysenck, 1982).

The PVVT task was aimed at detecting possible vigilance decrement. The ability to give accurate responses to the visual stimuli decreased over time. RTs clearly increased during the experiment. Earlier researches have found RTs to increase when drivers are obliged to stay awake and they are tested periodically 10 minutes at a time during 28 hours (Dorrian et al, 2008). This study supported earlier findings and furthermore revealed that RTs were mainly constantly increasing during the continuously measured 144 min. task. Reaction times followed a linear regression model in a statistically significant manner. Mackworth (1969) suggested that after the second half of hour there are no significant changes in RTs. However, in this research RTs continued to increase also after the first 60 minutes forming a linear function all the way to the end of task. There are also other views when RTs begin to increase, many of which consider the time being somewhere around the first half an hour (e.g. Kuikka, Pulliainen, & Hänninen, 2001;

Thiffault & Bergeron, 2002). Arruda (2003) was one to find different rhythmic patterns in sustained attention performance in different people. In this research, the interest was to examine the average vigilance performance, because that is interesting also when planning, for example, different safety equipments and warning systems for road vehicles. Here possible individual oscillations and detected momentary improvements in average RT behaviour did not have noticeable effect as the general trend was linear. Neither was there a clear turning point when RTs started more clearly to increase. Time on task, in this case meaning 144 minutes driving, predicted statistically significant increase in RTs.

4.3. Skin conductance

After vigilance decrement was indicated by RT increase, its' relationship with arousal indicated by SCRs, was studied. As noted in the introduction, the relationship between vigilance and arousal is not very clear. Arousal has much to do with the overall level of vigilance but it is not so directly connected with vigilance decrement (Parasuraman, 2000). In this research the SCR frequency was the greatest in quintiles 1 and 5 compared to quintiles 2, 3 and 4. In fast RTs (quintile 1) arousal frequency was a bit less than when RTs were the longest (quintile 5). Reaction times of average latency were accompanied with approximately equal amount of arousals. Also *SD*s of RTs were the greatest in quintiles 1 and 5. So, vigilance performance was good when arousal responses were frequent but interestingly also poor vigilance performance or vigilance decrement was accompanied with high frequency of arousals. The smallest SCR frequencies were found with RTs of average latency.

There were the greatest SCR frequencies in groups of misses and misclassifications compared to quintiles 1-5. The great frequency with misses suggests that the brain registered stimuli also when participants did not give objective responses. However, there could be at least three possible explanations for this. One explanation could be that SC shows spontaneous reactions. The second possibility is that participant noticed the stimulus but did not give a response for some reason. Speculating, it could be argued that they may have been too lazy or tired to respond or they were daydreaming while brain actually registered the stimulus and knew something should have been done. This is in line with earlier findings that also mere stimulus registration may evoke an arousal in SC (Blakeslee, 1979; Ward, Brickley, Sharry, McDarby, & Heneghan, 2004). A third possibility could be that the subject did not notice the stimulus because he/she was doing something irrelevant to the task, like adjusting equipment or scratching, and motor activity thus caused an increase in SC amplitude. If the participant did not notice the stimulus, some other activity may have caught driver's attention which is a serious threat on road traffic. It would be valuable to investigate from the videorecordings the cases with no response. This could provide relevant information of what makes drivers to focus their attention into some irrelevant activity while knowing that they should be performing a recorded and measured task, or indeed, driving a car and react to environmental stimuli when an exception from responding could be dangerous.

When participants misclassified stimuli, there was the greatest percentage of SCRs compared to every other RT quintiles or groups. It might be that participant noticed making a mistake and this caused a physiological arousal. Making a mistake or a threatening situation on road, resulting for example from driver's inattention, may have the same effect. As the acute moment has passed, driver may notice physiological arousal in his or her body.

Exploring trials that evoked an SCR (positive SC amplitude) revealed that SC amplitudes were mainly progressively greater when RTs were longer. When all the trials were included into analyses meaning also trials that did not evoke an SCR, SC and RT quintiles correlated in a statistically significant manner and SC amplitudes differed significantly between quintiles. However, as the latter procedure included also trials that did not evoke an SCR, it is thus not as informative and reliable as exploring only the trials with positive SC amplitude. The main result here was that in addition to RTs, also the mean magnitudes of SC increased along TOT. As the time goes, the greater arousals of ANS seem to be connected with giving a response. An interesting single finding was that when only positive SC amplitudes were considered there was a deviant result in case of quintile 4 as it did not differ significantly from quintile 1. Anyhow, when RTs were the longest (quintile 5), both SC amplitudes and SCR frequencies were the greatest (within quintiles 1-5). The overall arousal level of drivers may have been low when giving responses slowly and each response thus produced a relatively great peak in SC amplitude compared to situations when participants were alert enough to give responses in appropriate time.

Summarized, RTs were the fastest when SCR frequency, i.e. arousal was high. According to Andreassi (2007), new experiments have captured the same phenomenon. Also other researches have found that high arousal is connected with ability to act fast (Collet, Petit, Priez, and Dittmar, 2004) and that increased arousal is associated with improved attention (Eysenck, 1982). However, here also the slowest RTs were accompanied with high SCR frequencies. When arousal was at a moderate level, the performance was most steadily good. Earlier Yerkes and Dodson (1908) suggested that performance suffers if motivation, or here arousal, is either very high or very low. Here, good performance, i.e. fast RTs, was accompanied with relatively frequent but low amplitude SCRs while poor RT performance was accompanied with frequent and high amplitude SCRs. Measures of arousal were thus of a different quality in slow compared to fast RT quintiles.

4.4. Limitations and strengths of this research

This research included a 144 minutes vigilance task, which is relatively long in the field of vigilance studies. This provided more chances to find results from longer time periods, and to find out what happens after the first, often in vigilance studies caught, vigilance decrement has occurred.

Participants (n = 17) included only one woman, so the results may not be very well generalizable on women as keeping in mind that some studies have found women to be somewhat less aroused and slower in responding in general than men (eg. Giambra & Quilter, 1989). On the other hand, most truck drivers in Finland are men and they are the ones to drive long distances on monotonous environments day after day. For example a study of transportation organizations of Mikkeli conducted by MOL (2007) revealed that only 4,7 % of 571 truck drivers were women. In this research all subjects were studying professional truck driving which may make their performance in driving task not to be completely generalizable to regular driver populations. Personality traits were not considered here and it may be that in this sample participants were very similar with each other as same kind of traits may gravitate to this profession. But again, they are the ones to drive the heaviest vehicles on traffic where vigilance decrement may cause serious damages. Furthermore, there are controversial findings whether personality traits affect on vigilance performance in the first place (e.g. Eysenck, 1982; Mardaga Laloyaux, & Hansenne, 2006; Thiffault & Bergeron, 2002).

Technical limitations include the fact that the simulator did not contain a view from genuine outdoors, real steering wheel or other actual car or truck equipment. This might bother some of the participants and they might have been more motivated for better driving performance on a real motorway. On the other hand, the aim was to see vigilance decrement which can be caused as reliably with these equipment as in genuine circumstances.

Valuable information about vigilance decrement through voluntary RT task and involuntary SC were found well from real life replicated setting. These kinds of combined measures findings in long time performance could guide experts planning specific alertness related equipment in professional truck driving. Studies concerning the relationship between SC and vigilance performance are really needed as there already have been developments of applying SC monitoring into car or railway traffic (e.g. Neurocom, 2009).

4.5. Conclusions

This research supports earlier findings that excessive time of driving is a serious threat to road safety. Reaction times linearly increased already during 144 minutes driving. As there are plans to use SC measuring to reflect driver’s ability to drive safe on traffic, the connection between these autonomic and behavioral dimensions is an important field of study. Some studies in the field have already been done and for example Dorrian et al (2008) found that RTs and driving performance were not clearly connected with SC variations when measured periodically during a 28 hours imposed keeping awake. In this research arousal, indicated by SC, was connected to the latency of RTs i.e. vigilance performance. However, the connection was not completely straightforward. Vigilance decrement or inattention indicated by misses and misclassifications was accompanied with highest SCR frequencies. Of course it is possible that arousals occurred just after, for example, making a mistake. Within actual RT quintiles the greatest arousal frequencies were connected with the slowest and fastest RTs. High arousal frequency thus was connected with fast reacting, but not only with it. Furthermore, mean SC amplitudes of SCRs were the greatest with slowest RTs. So, vigilance performance was the best when arousal responses occurred frequently but their mean amplitude remained relatively low. The worst performance was detected when arousal responses were frequent and their amplitudes were great. Relatively stable arousal state was accompanied with quite stable RT performance.

Clear performance degradation was detected though all subjects were non-sleep deprived, had no sleep deficits and were studying professional driving. This profession group could be expected to be somewhat more able to manage demanding situations, like keeping alertness in a sufficient level to drive safe, compared to common population. However, TOT predicted a significant linear increase in RTs. Kind of an arousing component might be helpful on road or in vehicles to prevent the alertness to reduce under optimal level where orienting attention appropriately and accurate reactions are threatened. Too high level of arousal may also be a risk for making mistakes or, at least in experimental conditions, misclassificating perceived stimuli. Stable vigilance performance or ability to give responses in reasonable time seems to be associated with relatively stable physiological alertness. In prolonged driving, even if theoretically possible, continuous high manifestation of the sympathetic division of ANS might thus not be the best option for safe driving and accurate reactions. Probably the best alternative in sustained attention circumstances would be a stable and balanced state in ANS activity. Driver’s psychophysiological state should be considered as a whole in evaluating alertness and ability to drive in a safe manner. Combining behavioural and physiological components could help to find a functional way to reduce accidents caused by driver’s fatigue and to enhance road traffic safety.

In future it would be valuable to investigate RT performance on different kinds of samples or explore more specifically individual RT curves. More precise analyses of SC data would also provide valuable information about arousal intensities during a long task, like when does the arousal actually occur related to visual stimuli and voluntary reacting. Additionally, it would be productive to explore the sequences when driver does not give a response. If there is neither SCR, driver probably does not notice the stimulus and may even be in sleep. Here misses produced relatively high amount of SCRs suggesting that participants registered stimuli, performed some movement or became tense during a miss or right after it. The proper observation of video recordings could reveal what happens during misses both in the situations when ANS reacts and when it does not. It might have also been revealing if performance in the actual driving task was analysed here parallel with behavioural and autonomic measures. The combined measures of behavioural and autonomic aspects of a driver could provide relevant information of the fatigue. Further studies are needed to establish more accurate relationship between these dimensions. Overall findings support the idea that autonomic and behavioural measures together could be an effective way to monitor driver's alertness state more reliably or broadly than either measure alone.

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