In Proceedings of the 32nd EAAP Conference in Cascais/Portugal, 26-30.09.2016.

Differential Effects of Sleep Deprivation on Cognitive Performance

Hans-Juergen Hoermann, Mona Mischke, Eva-Maria Elmenhorst, & Sibylle Benderoth

German Aerospace Center (DLR), Institute of Aerospace Medicine, Hamburg/Cologne, Germany

Abstract. The study examines the question whether individual vulnerability to effects of sleep deprivation on cognitive and psychomotor performance is related to personality traits. 46 participants stayed for 13 days in DLR's sleep laboratory AMSAN. Sleep was restricted totally or partly every three nights. The level of performance was monitored in three-hour intervals with a cognitive test battery. Most participants showed the strongest performance decrements after 26 and 32 hours of sleep deprivation. Especially for tests of sustained attention, calculated change scores were negatively related to extraversion as measured by the Freiburger Personality Inventory. The findings confirm parts of Eysenck's theory of personality that introverts due to their higher cortical arousal level need less external stimulation to perform.

Keywords: sleep deprivation, cognitive performance, resilience, extraversion

Introduction

According to the National Transportation Safety Board's (NTSB) statistics of transportation accidents and incidents operator fatigue is regarded as one of the most serious safety hazards in civil aviation since over two decades (Rosekind, 2013). Ultra-long range flights, increasing levels of automation and societal demands for 24 hours service availability on seven weekdays have amplified the prevalence of fatigue related operational errors. Regulators have recently updated their flight time limitations for flight crews on duty. However, these time limitations have been subject to strong debates because they are not always compatible with scientific research results and because of the fact that individual levels of fatigue can hardly be regulated (Graeber, 2008; Moebus, 2008; Hoermann, Tsang, Vidulich & Alexander, in prep).

Many laboratory studies with hundreds of subjects provided empirical evidence that the level of cognitive performance is strongly affected by conditions of restricted sleep. Two recent meta-studies gave an overview of the findings (Lim & Dinges, 2010; Wickens, Hutchins, Laux, & Sebok, 2015). Decrements in more realistic behavioural tasks could also be confirmed outside of the laboratory. In Table 1 we summarize different areas of human performance, which are demonstrably affected by fatigue. The table gives examples of simple and complex tasks where sleep disruptions led to declining performance. The list is not complete.

The extent of performance decrements varied from study to study. Besides the performance area itself the strongest moderating factor for the effect sizes seemed to be the time awake (Lim & Dinges, 2010). However, the influence of sleep duration and time awake on performance seems to be subject of considerable inter-individual differences. As Van Dongen, Vitellaro, & Dinges (2005) argued, "Evidence is accumulating that certain aspects of sleep/wake-related variability—such as sleep duration, daytime sleepiness, and vulnerability to the effects of sleep loss—involve trait characteristics in healthy populations and among sleep-disordered patients" (p 479). The nature of such sleep/wake related traits as well as their relationship remains largely unknown (see also Van Dongen, Baynard, Maislin, & Dinges, 2004; Van Dongen & Belenky, 2009; Rupp, Wesensten, & Balkin, 2012).

Table 1: Areas of human performance affected by fatigue

Cognitive Performance	
Simple attention Complex attention Processing speed Working memory, short-term memory Logical reasoning and crystallized intelligence	Lim & Dinges, 2010
Reaction times and vigilance (sustained attention)	Van Dongen & Dinges, 2005
Auditory attention	Binks et al., 1999
Information gathering and processing	Ratcliff & Van Dongen, 2009
Declarative knowledge access	Gunzelmann et al., 2012
Complex Behaviours	
Recognition of emotions	Killgore et al., 2011
Decision making	Petrilli et al., 2006
Flight performance, instrument scanning	Caldwell et al., 2004 Previc et al., 2009

In our study we examined the question whether the individual vulnerability to effects of sleep deprivation is related to stable personality characteristics. According to Eysenck's personality theory (Eysenck, 1981, 2006), we expect that extraverts show greater performance impairment than introverts. Due to their lower cortical arousal level, extraverts habitually prefer situations with a higher degree of external stimulation, which is not provided in a sleep deprivation experiment. Therefore, we expect personality effects to be especially prominent in longer and more monotonous supervisory tasks.

Method

Participants and procedure:
In the DLR sleep laboratory cognitive performance of 46 volunteers (20 female, mean age 26.5 years (*SD* = 5.1 years) was monitored during 12 consecutive days and nights. All participants were mentally and physically in good conditions with no recent history of sleep disorders, medication and drug or alcohol abuse. After one adaptation and two baseline nights, participants' sleep was restricted to induce different levels of performance impairment (total sleep deprivation (TSD, 38h awake), partial sleep deprivation (PSD, 4h sleep), and partial sleep deprivation after moderate alcohol intake). Two nights of recovery were granted between sleep restriction conditions that were administered in a cross-over design. During wakefulness participants conducted a battery of performance tests in 3-hour intervals (in total 63 sessions). In advance of the study all participants received a comprehensive briefing and intensive training in all performance measures. Further details can be found in Elmenhorst Hoermann, Oeltze, Pennig, Rolny, Vejvoda, Staubach, & Schießl (2013).

Measures:
Personality: The Freiburger Personality Inventory (FPI; Fahrenberg, Hampel & Selg, 2001) was administered to the subjects prior to the study as part of the recruitment procedure. The FPI measures ten personality scales with altogether 138 items. Extraversion and Neuroticism

are measured as additional traits in approximation to Eysenck's theory of personality. The scale Extraversion consists of 14 yes/no items.

Cognitive performance: Cognitive performance of the subjects was measured with a computerized test battery consisting of the Psychomotor Vigilance Task (PVT), Unstable Tracking (UTT), Perceptual Speed (PSP), Mental Concentration (MCO) and Spatial Orientation (SPO). The PVT was presented in two versions: a 10-minutes and a 3-minutes version. While the PSP, MCO, and SPO are pure mental aptitude tests, the PVT and the UTT involve psychomotor performance.

Analysis:
In order to test our hypotheses individual changes of performance were measured using the Reliable Change Index (RCI) of Jacobson & Truax (1991). Compared to simple differences the RCI has the advantage to compensate for unreliability of measurement, which is often a problem when change is measured by differences of test scores. With the RCIs we compared performance scores of the second baseline day to the 9am and 3pm performance scores after TSD. RCIs are distributed like *z*-scores with a mean of zero and a standard deviation of 1. All RCIs were converted so that negative scores indicate a decrease of performance in all cognitive tests.

Results

After 26 hours and 32 hours time awake most participants showed strong performance decrements in all tasks except for the test of Perceptual Speed. An example of the RCIs is presented in Figure 1 for the 10 minutes PVT-version (PVT10) in the entire sample after being 26 hours awake. The inter-individual variation of the change scores is large as can be seen from the chart. The RCIs for all cognitive tests are negative and significant at the 1% probability level, except for the PSP.

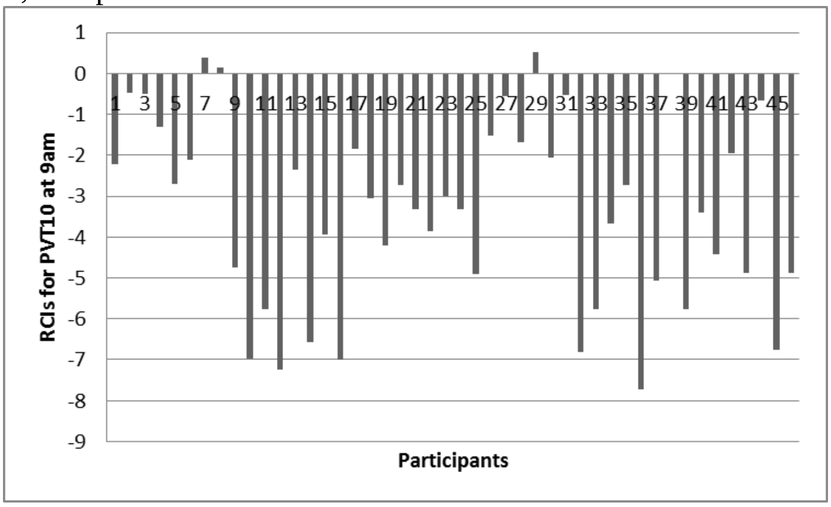

Figure 1: RCIs for performance in PVT10 after 26 hours time awake (mean RCI = -3.35)

In terms of temporal stability correlations were calculated between the RCIs of the same test after 26 hours and 32 hours time awake. The coefficients are all statistically significant as follows: r(PSP) = .31*, r(MCO) = .76**, r(SPO) = .57**, r(UTT) = .61**, r(PVT10) = .67**, r(PVT3) = .60**.

On the basis of FPI Extraversion scores participants were assigned to two extreme groups of extraverts (n=15) and introverts (n=8). Due to the screening process prior to the experiment the distribution was slightly skewed towards participants with higher scores on Extraversion.

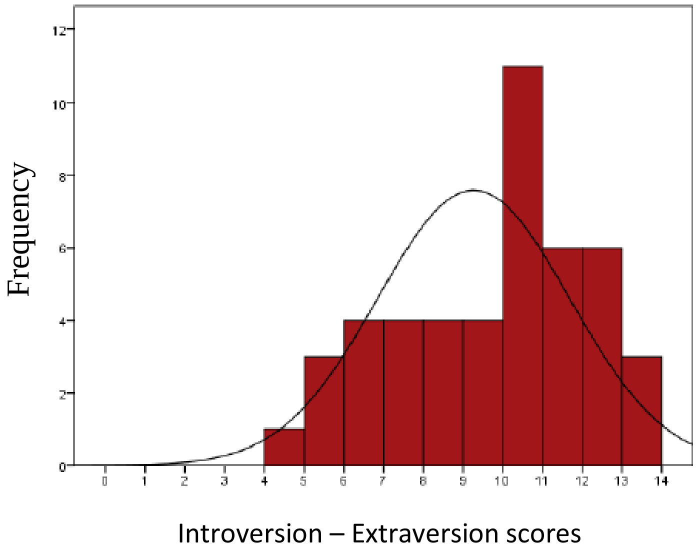

Figure 2: Frequency distribution of Introversion - Extraversion (N=46)

Group membership was used as the between-subjects independent factor in MANOVAs with the RCIs of the five performance tests as dependent variables. The multivariate F-test was significant with F(5,17) = 4.65, p = .007, η_p^2 = .58 after 26 hours time awake and F(5,17) = 3.74, p = .018, η_p^2 = .52 after 32 hours time awake. Univariate F-tests showed that the moderating effect of Introversion-Extraversion was more pronounced for the two tests with a psychomotor component (UTT: F(1,21) = 4.47, p = .047, η_p^2 = .18; PVT: F(1,21) = 16.59, p = .001, η_p^2 = .44) than for the pure mental tests. Figure 3 illustrates the group differences for the PVT versions with 10 and 3 minutes duration.

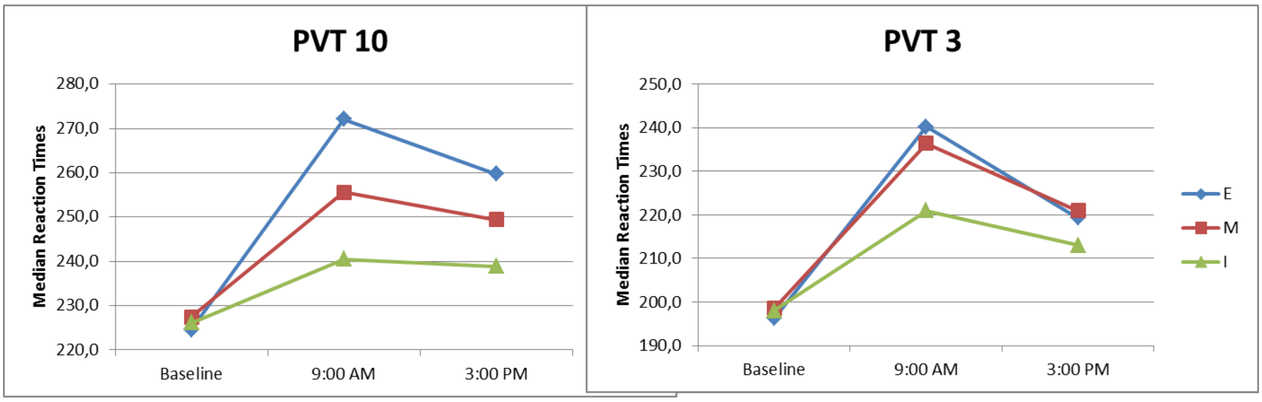

Figure 3: Group comparison of PVT median reaction times at baseline and after TSD. E = Extraverts, I = Introverts, M = middle group.

From a visual inspection of Figure 3 it seems that performance in the longer, more monotonous version of the PVT was more strongly affected by group membership than the short 3-minutes version. However, a two-way mixed design ANOVA found no significant effects, neither for the test version (F(1,19) = 1.11, p = .31) nor for the interaction test version X group membership (F(1,19) = 0.94, p = .34). Only the between-subjects factor for the group membership was significant (F(1,19) = 9.44, p = 0.006, η_p^2 = .33).

Discussion/Conclusions

Our research confirmed that the extent of performance impairment due to effects of sleep restriction is subject to large inter-individual differences. Performance in four out of five cognitive functions was significantly reduced after 26 and 32 hours time wake. Only the Perceptual Speed Test remained relatively unaffected after total sleep deprivation. A reason for this finding could be that a slightly different test version was used for the practice runs prior to the experiment. Therefore, the quality of training was not equal compared to the other tests. This could have reduced the reliability of the change scores for PSP and hence the probability to detect significant performance decrements (see Elmenhorst et al., 2013).

Individual change was measured with RCIs according to Jacobson & Truax (1991). RCIs after 26 hours and 32 hours time awake appeared rather stable and therefore confirm the trait-like character of the sleep restriction effects. With mixed model MANOVAs we examined whether the extent of performance change was significantly related to group membership based on the Introversion-Extraversion scale of the FPI. The multivariate effects were significant for both points of time with medium effect sizes. Participants who scored low in this scale (i.e. introverts) appeared more resilient against effects of sleep restriction when compared to the extraverts. This finding is in line with other studies (e.g. Taylor & McFatter, 2003; Killgore et al. 2011; Rupp et al. 2012) and confirms the assumption of Eysenck's theory of personality that extraverts have a lower cortical arousal level, which leads to performance deficits in monotonous tasks with little outside stimulation. In our study the relationship of Extraversion to the vulnerability of sleep deprivation effects was largest for the Psychomotor Vigilance Task, a simple reaction time task with only on/off visual signals to be monitored during the test period.

On the other side the evidence for our expectation that longer test duration of the PVT creates a higher degree of monotony and hence should lead to even higher vulnerability of extraverts could not be confirmed conclusively. When we compared the ten minutes to the three minutes PVT in relation to Introversion-Extraversion the effect was not significant. Rather than test-duration, the fact that a test involved a psychomotor function seemed to augment the relationship between personality and performance impairment after sleep restriction.

Acknowledgements

This paper is based on the Bachelor Thesis of Mona Mischke at the Leuphana University of Lüneburg as submitted on 26th March 2015.

References

Binks, P.G, Waters, W.F., & Hurry, M. (1999). Short-term total sleep deprivation does not selectively impair higher cortical functioning. *Sleep*, *22*(3), 328-334.

Caldwell, J. A., Caldwell, J. L., Brown, D. L. & Smith, J. K. (2004). The Effects of 37 Hours of Continuous Wakefulness On the Physiological Arousal, Cognitive Performance, Self-Reported Mood, and Simulator Flight Performance of F-117A Pilots. *Military Psychology, 16* (3), 163–181.

Elmenhorst, E.-M., Hoermann, H.-J., Oeltze, K., Pennig, S., Rolny, V., Vejvoda, M. Staubach, M. & Schießl, C. (2013). *Abschlußbericht zum Projekt FIT*. Cologne: German Aerospace Center (DLR).

Eysenck, H.J. (Ed.) (1981). *A model for personality*. Berlin: Springer.

Eysenck, H.J. (2006). *The biological basis of personality* (first published 1967). New Brunswick, N.J.: Transaction Publishers.

Fahrenberg, J., Hampel, R. & Selg, H. (2001). *Das Freiburger Persönlichkeitsinventar. FPI-R; Manual* (7th edition). Goettingen: Hogrefe Verlag für Psychologie.

Graeber, R.C. (2008). Fatigue Risk Management Systems within SMS. *Proceedings of the FAA Fatigue Management Symposium: Partnerships for Solutions,* Vienna, VA: June 17-19.

Gunzelmann, G., Gluck, K. A., Moore, R. L. & Dinges, D. F. (2012). Diminished access to declarative knowledge with sleep deprivation. *Cognitive Systems Research, 13* (1), 1–11.

Hoermann, H.-J., Tsang, P.S., Vidulich, M.A., & Alexander, A.L. (in prep.) Researcher role in aviation operations. In M.A. Vidulich, P.S. Tsang, & J.M. Flach (Eds.) *Advances in Aviation Psychology (Vol. 2)*. New York, Routledge.

Jacobson, N. S. & Truax, P. (1991). Clinical significance: a statistical approach to defining meaningful change in psychotherapy research. *Journal of Consulting and Clinical Psychology, 59* (1), 12–19.

Killgore, W. D. S., Grugle, N. L. & Balkin, T. J. (2011). Sleep deprivation impairs recognition of specific emotions [Abstract]. *Sleep (Abstract Supplement), 34,* A107.

Lim, J. & Dinges, D. F. (2010). A meta-analysis of the impact of short-term sleep deprivation on cognitive variables. *Psychological Bulletin, 136* (3), 375–389.

Moebus, P. (Ed.) (2008). *Scientific and medical evaluation of flight time limitations* (final report). TS.EASA.2007.OP.08. Moebus Aviation, Zurich/Switzerland.

Petrilli, R.M., Thomas, M.J.W., Dawson, D. & Roach, G.D. (2006). The decision-making of commercial airline crews following an international pattern. In: *Proceedings of the Seventh International AAvPA Symposium*, Manly, 2006.

Previc, F. H., Lopez, N., Ercoline, W. R., Daluz, C. M., Workman, A. J., Evans, R. H. et al. (2009). The Effects of Sleep Deprivation on Flight Performance, Instrument Scanning, and Physiological Arousal in Pilots. *The International Journal of Aviation Psychology, 19* (4), 326–346.

Ratcliff, R. & Van Dongen, H. P. (2009). Sleep deprivation affects multiple distinct cognitive processes. *Psychonomic Bulletin & Review, 16* (4), 742–751.

Rosekind, M. (2013). Managing fatigue in aviation. *Aviation Safety Coordinators*, NTSB, July 24, 2013.

Rupp, T. L., Wesensten, N. J. & Balkin, T. J. (2012). Trait-like vulnerability to total and partial sleep loss. *Sleep, 35* (8), 1163–1172.

Taylor, D. J. & McFatter, R. M. (2003). Cognitive performance after sleep deprivation: does personality make a difference? *Personality and Individual Differences, 34* (7), 1179–1193.

Van Dongen, H. P., Baynard, M. D., Maislin, G. & Dinges, D. F. (2004). Systematic interindividual differences in neurobehavioral impairment from sleep loss: evidence of trait-like differential vulnerability. *Sleep, 27* (3), 423–433.

Van Dongen, H. P. & Belenky, G. (2009). Individual Differences in Vulnerability to Sleep Loss in the Work Environment. *Industrial Health, 47* (5), 518–526.

Contact Information

Hans-Juergen Hoermann, PhD
Sportallee 54a
D-22335 Hamburg, Germany
Hans.hoermann@dlr.de