Psychopharmacology

10.1007/s00213-003-1714-5

Original Investigation

Effects of MDMA (ecstasy), and multiple drugs use on (simulated) driving performance and traffic safety

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Received: 25 April 2003 **Accepted:** 12 August 2003 **Published online:** 9 January 2004

Abstract

Rationale The effects of MDMA on driving behaviour are not clear, since the direct effects of MDMA on cognitive performance are reported as not generally negative.

Objectives To assess in an advanced driving simulator acute effects on simulated driving behaviour and heart rate of MDMA, and effects of polydrug use.

Methods A group of young participants who had indicated that they regularly used MDMA were asked to complete test rides in an advanced driving simulator, shortly after the use of MDMA, just before going to a party. They were tested again after having visited the "rave", while they were under the influence of MDMA and a number of different other active drugs. Participants were also tested sober, at a comparable time at night. Separately, a control group of participants was included in the experiment.

Results Driving performance in the sense of lateral and longitudinal vehicle control was not greatly affected after MDMA, but deteriorated after multiple drug use. The most striking result was the apparent decreased sense for risk taking, both after MDMA and after multiple drug use. This was clear from gap acceptance data, while the ultimate indicator of unsafe driving, accident involvement or even causation, was increased by 100% and 150%, respectively.

Conclusions Driving under the influence of MDMA alone is certainly not safe; however, driving back (home) after a dance party ("rave") where MDMA users regularly combine MDMA with a host of other drugs can be described as extremely

dangerous.

Keywords Ecstasy - MDMA - Safety - Driving - Cognitive performance

Introduction

MDMA (±3,4-methylenedioxymethamphetamine; ecstasy) is a popular dance drug. MDMA is predominantly used for its socially facilitating and euphoric effect (Parrott and Stuart *1997*). Engaged in mega-dance or house-party festivities, (mainly) younger people use MDMA and other drugs that keep them "in the right mood". Acute effects of MDMA on cognitive performance include reduced accuracy in performance (Morgan *1998*), while chronic use produces lack of concentration (Vollenweider et al. *1998*), depressed mood, anxiety, and impulsiveness (Morgan *2000*). Basal aspects of cognitive performance, such as visual-spatial performance, are not acutely affected (Krystal et al. *1992*; Parrott and Larsky *1998*), although there are indications that there are long-term effects on memory and reaction times by heavy users (Verkes et al. *2001*). So far, acute effects of MDMA on car driving performance have been documented only with respect to skills that are related to car driving, and in the form of case studies (Logan and Couper *2001*). Schifano (*1995*) gave some examples of extreme driving behaviour leading to traffic accidents after dance parties involving, amongst others, MDMA use. Although MDMA is suspected to have some influence on the control level of performance (e.g. accuracy in lane-keeping), main effects are expected on risk-taking and judgement in complex situations (Morgan *1998*).

A driving simulator test (Van Wolffelaar and Van Winsum *1995*) was performed before and after participants visited some festivity. Whereas the participants were instructed to use only MDMA before the festivity, during the festivity they were allowed to do as usual and use anything they liked, behaving as they would normally do. The capability to drive a motor vehicle after such events is of major interest, because of the variety in psychoactive compounds and their effects on behaviour. There is anecdotal evidence that at least some of the visitors to such festivities drive a motor vehicle afterwards.

Materials and methods

Twenty-three participants, 17 male and six female, were approached, first via a street-corner worker acting as intermediate, and by spreading the word. All participants had held a driving licence for at least 2 years and indicated that they used MDMA regularly (i.e. at least 10 times in the past 2 years). Participants were asked if they were willing to participate in a study on the effects of MDMA on an evening on which they already had the intention to use MDMA. Accordingly, MDMA was not provided, but self-administered by a sample of participants from the population of regular MDMA users. All participants personally bought the MDMA tablets themselves (reimbursed by the institute), one for ingestion and one for substance analysis. To ascertain that the sample ingested and the sample for analysis were from the same batch, and hence were the same strength, the participants were instructed to select two identical tablets, and thereupon randomly select one for ingestion and one for analysis.

Participants were invited to the institute 4 times. During the first visit the procedure was explained, informed consent was obtained and a first practice ride was completed in the simulator. A medical checklist was completed and submitted to a medical doctor for approval of inclusion. During the night of a party, two rides were made, one approximately 1 h after ingestion of MDMA, and one after the party (much) later.

Participants were instructed to consume one MDMA tablet before the first test ride, while between the first and second ride they were allowed to take any psychoactive substance in any combination and dosage they would normally do. On a separate evening, a non-drugs test ride was completed at the same hour as the first MDMA ride, and on that day no drugs were allowed. The order of the MDMA-multiple drug condition was fixed, but the order of MDMA/multiple-drug and non-drug ride was balanced across participants.

As there are indications that users of MDMA differ from non-users (similar to cannabis users; Rodgers *2000*), a control group was separately added to the study. Both the practice and the nocturnal non-drug rides were completed by the 13 participants of the control group, who had no experience with and did not consume MDMA.

The Ethical Committee of the Department of Psychology of the University approved the experimental protocol.

Procedure

Participants completed test rides in a fixed-base driving simulator consisting of a car with original controls linked to a Silicon Graphics computer, registering driver behaviour, and computing the road environment. The road environment was projected on a semi-circular screen. Other vehicles in the simulated world interacted with the simulator car autonomously and behaved according to hierarchically structured decision rules that are based on human driving behaviour (Van Wolffelaar and Van Winsum *1995*). Four types of measures were registered during the experiment: performance, physiology, self-reports, and control measures.

Performance measures

Performance measures are in principle speed or accuracy measures, reflecting performance at the operational and tactical levels (Michon *1985*), indicating lateral and longitudinal vehicle control, frequently used measures for vehicle handling that have been shown to be sensitive to the effects of sedative medicinal drugs (Brookhuis et al. *1990*).

Speeds of lead and following car during car following were analysed on coherence (Brookhuis et al. *1994*), resulting in a measure of delay in response to speed changes (De Waard and Brookhuis *2000*), sensitive to medicinal drugs (Brookhuis et al. *1993*).

Gap acceptance was assessed twice, once while crossing a priority road with traffic coming from left and right, and once while turning left with approaching traffic. Additionally, participants' response to a traffic light turning yellow was assessed (De Waard et al. *1999a*).

Once on the motorway, traffic intensity gradually increased until lead traffic had to brake to a standstill. This scenario passed twice. Participants' reaction time was measured in this situation, which can lead to crashes, i.e. the ultimate measure of unsafe driving.

Self-report measures

After each ride, participants were required to rate the amount of effort (Zijlstra *1993*) they had to invest during driving and their own driving performance quality (Brookhuis et al. *1985*) on standard one-dimensional scales.

Physiological and control measures

Questionnaires on used drugs and on self-experienced psychological and physiological effects were administered, similar to Davison and Parrott (*1997*).

Participant's ECG was registered, i.e. the inter-beat-interval (IBI), and from IBI the average heart rate and the 0.10 Hz component of heart rate variability were determined, reflecting mental effort during driving (Kramer *1991*; Backs and Seljos *1994*; De Waard et al. *1999a*). A distinction between two modes of cardiac control is important with respect to interpretation of heart rate and heart rate variability changes during mental effort and stress: 1) parasympathetic (vagal) and sympathetic output to the heart, directly controlled by the hypothalamus, and 2) mediation by baroreflex activity (Mulder *1992*; Mulder et al. *2003*). The (0.10 Hz component of) heart rate variability, baroreflex mediated, is specifically related to mental effort, whereas heart rate changes are susceptible to many influences (Mulder et al. *2003*).

Participants were breathalysed and also required to supply a urine sample to perform a general toxicological screening including amphetamines, cannabinoids, cocaine, opiates and benzodiazepines. Oral fluid samples were collected, providing a non-invasive alternative matrix for the quantitative determination of amphetamine analogues (Samyn et al. *1999*). Biological samples were deep-frozen and analysed separately (Samyn et al. *2002*).

Results

Three subjects decided to withdraw from the experiment half-way through. In total, 20 participants in the experimental group, 15 male and five female, completed all drug and non-drug conditions; their average age was 27 years (SD 4.5) and average mileage 17,000 km/year (SD 14,000). On average, they had used MDMA 26 times (SD 27, range 2–100) for a total of 40 tablets (SD 45, range 2–150). Sixty percent had driven a car at least once while under the influence of MDMA, on average 8 times (SD 14, range 0–50). Most participants from the experimental group had ample experience with other drugs, and combining MDMA with these drugs.

Results on self-experienced psychological and physiological questionnaires were comparable with the study of Davison and Parrott (*1997*). Physiological effects such as high heart rate, unsteadiness and headache were also occasionally reported, as were increased heart rate, hyperthermia, dilated pupils, a dry mouth, increased sweating, and tingling skin. Subjectively experienced effects were increased perception of sound, touch, and colour, especially after multi-drug use. Common effects such as being more talkative after MDMA were also confirmed.

In the control group, 13 non-drug-users completed the non-drug test rides; average age 24 years (SD 5.5), average mileage 14,000 km/year (SD 4000).

MDMA dosage and other drugs used

The average consumed dosage MDMA was 59 mg (SD 22, range 25–98 mg MDMA). This is a relatively low dose; the normal average dose is 120 mg (Logan and Couper *2001*). After the first MDMA ride, the majority (70%) took more MDMA before the multi-drug ride. All participants additionally took other drugs in that time span, marihuana (80%) and alcohol (90%) most commonly. In Table 1 all substances used by the participants are listed.

Table 1 Effects of MDMA (ecstasy), and multiple drugs use on driving performance and traffic safety. Proportion of subjects per condition indicating use of a substance (*n*=20 for the

experimental group, *n*=13 for the control group)

Drug used	Group, condition			
	Experimental, MDMA	Experimental, multi-drug	Experimental, non-drugs	Control, non-drugs
Alcohol	30	90	15	15
Marihuana	35	80	30	0
Tobacco	45	80	45	15
MDMA	100	70*	0	0
Amphetamine (speed)	0	30	0	0
Caffeine	25	25	45	0
Cocaine	0	10	0	0
Psylocibine	0	10	0	0
GHB	0	10	0	0
LSD	0	5	0	0
5-HTP	0	5	0	0
Heroine	0	0	0	0
Crack	0	0	0	0
Nitrous oxide	5	0	0	0

[a]Additional intake of MDMA

In the experimental group breath analysis showed a blood alcohol concentration of 0.00‰ for all participants in the non-drug and MDMA condition. In the multi-drug condition, the average BAC was 0.39‰ (SD 0.39, range 0.00–1.09).

In the control group, with the exception of one subject in whom breath analysis indicated 0.11‰, the measured BAC was always zero.

Performance measures

The standard deviation of lateral position (swerving) increased significantly [$F(1,18)=5.5$, $P=0.031$] with 0.03 m in the multi-drug condition compared to the non-drug condition, both in the built-up area and on the motorway. From non-drug to MDMA to multi-drug, an increase in average speed was found in the built-up area of, respectively, 2.5 and 7.1 km/h. Standard deviation of the driving speed during the test rides also significantly increased from non-drug to MDMA to multi-drug [$F(1,19)=4.8$, $P=0.040$ and $F(1,19)=8.83$, $P=0.008$]. Control and experimental groups did not differ in the non-drug conditions [$F(1,31)=1.95$, NS].

The gap acceptance test in the multi-drug condition showed significantly smaller accepted gaps than in the non-drug condition [$F(1,18)=4.75$, $P=0.043$]. Although the average time-headway to the car in front was smaller in the multi-drug condition compared with the non-drug condition, this effect was not significant. Differences between control group and experimental group were not significant either, whereas average time headway was smaller in the control group, as was variance in headway.

On the busy part of the motorway, cars ahead stopped to a standstill twice. In both conditions, movement time and reaction time were determined. No effects on the averages of parameters were found: 0.76 s and 1.64 s, respectively. However, standard deviation in RT between participants increased from 0.35 (non-drug condition) to 0.52 (MDMA condition) to 0.88 (multi-drug condition). On average, the standard deviation in RT for the control group was 0.39.

The ultimate indicator of driving safely is the absence of crashes. Although crashes are relatively rare in real traffic, in the simulator on the motorway section where lead cars suddenly braked, sometimes accidents happened. None of the control group participants had ever had a crash. During two of the 20 non-drug rides with the experimental group crashes occurred; while under the influence of MDMA, the simulator car collided with another car (100% increase) 4 times. Under the influence of multiple drugs, participants crashed 5 times.

Physiological measures

The pattern of average heart rate in beats per minute is remarkably similar in all conditions for different sections (city driving, gap acceptance, car-following, the traffic-light scenario, driving on the motorway and a rest, see Fig. 1). After drug use, heart rate was significantly increased, after multiple drugs on average up to 18 beats per minute. Heart rate was also higher at the points where a decision had to be taken, in particular at the two gap acceptance tasks.

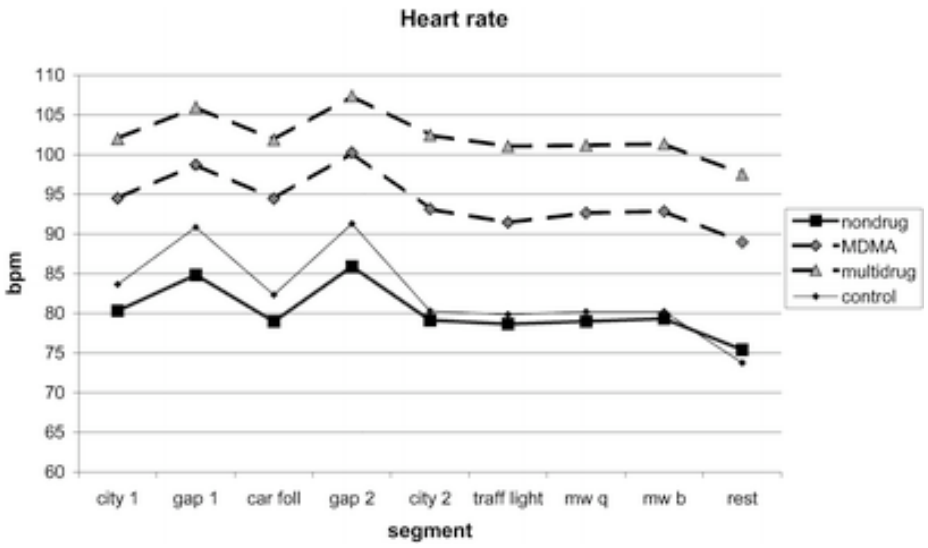

Fig. 1 Effects of MDMA (ecstasy), and multiple drugs use on driving performance and traffic safety. Average heart rate while driving over the different sections. *Gap 1* gap acceptance task of crossing a junction, *gap 2* gap acceptance task while turning right, *mw q* motorway quiet, *mw* b motorway busy, *rest* while resting

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Data for heart rate variability in the 0.10 Hz frequency band (Fig. 2) were normalised

(Van Roon *1998*), reflecting mental effort (Mulder *1992*). This was clearly the case at the first gap acceptance test, where energy was suppressed (indicative of increased mental effort). The second gap acceptance test showed less consistent results; however, during rest, energy increased again. The reduced variability in the multi-drug condition may suggest either increased effort or a ceiling effect, heart rate in this condition being extremely high.

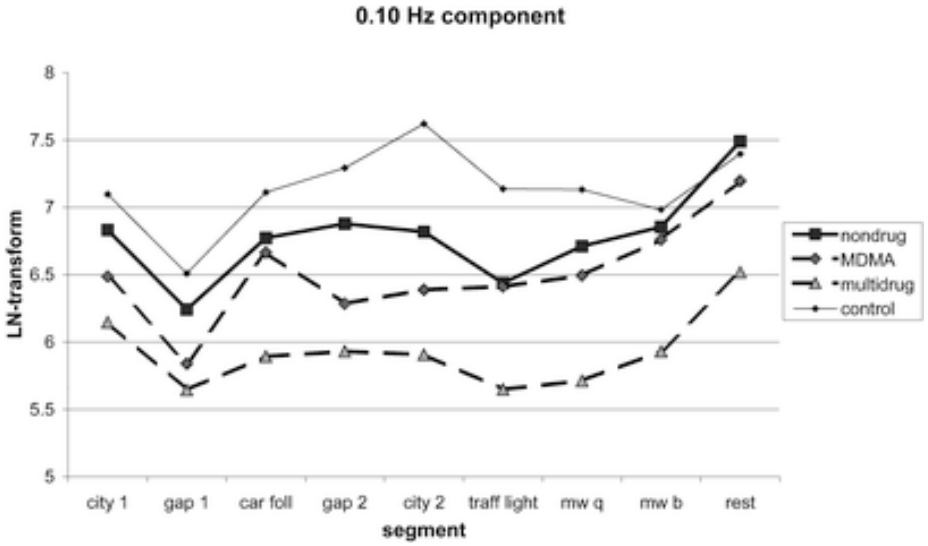

Fig. 2 Effects of MDMA (ecstasy), and multiple drugs use on driving performance and traffic safety. Logarithmic transformation of energy in the 0.10 Hz frequency band of heart rate variability. Energy in this band is suppressed in condition of mental effortful task performance. *Gap 1* gap acceptance task of crossing a junction, *gap 2* gap acceptance task while turning right, *mw q* motorway quiet, *mw b* motorway busy, *rest* while resting

Self-report measures

Self-reported effort increased on a scale from 0 to 150 from 40.2 in the non-drug condition to 47.6 in the MDMA condition to 50.7 in the multi-drug condition [drug versus non-drug is significant; $F(1,29)=5.02$, $P=0.037$]. The control group indicated an average of 49.1 [$F(1,31)=1.83$, NS].

On the driving quality scale, ranging from +100 (extremely well) to –100 (extremely badly), the control group on average rated normal driving (0.2). The experimental group in the non-drug condition indicated driving as better than normal (+16.5), under the influence of MDMA about normal (+3.8), and under the influence of multiple drugs lower than normal (–4.6). The difference between non-drug state and the two drugs conditions is significant [$F(1,19)=5.13$, $P=0.035$].

Urine analyses

Urine analyses were performed to confirm the self-reported drug use (Table 1) and detect non-reported psychoactive substances. In general, screening results of urine samples in the multi-drug condition matched the reported drug intake rather well: the presence of LSD, psilocybin, cocaine and amphetamine in addition to MDMA was confirmed. In the multiple-drug condition, three participants provided a urine sample positive for MDEA in addition to MDMA. In three other participants, in both drug conditions, urine analysis revealed the presence of amphetamine or MDEA instead of MDMA.

Two participants had a positive MDMA result in urine in the non-drug condition. One had reported the use of MDMA on the day before, the other did not report the use of MDMA in the week before the test ride. One subject was positive for amphetamine.

Cannabis was reported in 30% of participants in both the drug and non-drug conditions. Urine analysis revealed cannabis use in 60% of cases, but since marihuana can be detected in urine for several weeks in regular users, this was not proof of recent use.

Two participants who admitted intake of cocaine before the multiple-drug test ride, were also positive for cocaine before the MDMA test ride; one even showed a positive result in the non-drug condition.

For the participants in the control group, all screens were negative.

Oral fluid analyses

The sample volume was extremely low in this study, especially in the MDMA conditions (50–100 μl), requiring the use of a very sensitive technique and only allowing detection of amphetamines (Samyn et al. *2002*). Qualitatively, the correlation between confirmatory results for amphetamines in urine and oral fluid was excellent. Quantitative measurements in oral fluid were interpreted using the proposed SAMHSA workplace drug testing cut-off level of 50 ng/ml for the relevant amphetamines (Samyn et al. *2002*). Concentrations ranged from 65 ng/ml to 5519 ng/ml (median 1354 ng/ml). Oral fluid concentrations indicated the degree of impairment to a better extent than urine levels (Samyn et al. *1999*).

Discussion

The main conclusion must be that from a health point of view, using MDMA is not recommended, for many reasons. Most striking of all was the number of crashes in the multiple drugs session (25% of all rides) and in the MDMA session (20%), at night and early in the morning. However, the experimental drug group had crashes in the non-drug control rides as well (10%). The control group had no crashes. This finding strongly suggests that the group of MDMA users differs from the control group in more ways than just drug use. In a birth cohort study of 907 young New Zealanders (Horwood and Fergusson *2000*; Fergusson and Horwood *2001*), the relationships between cannabis use and alcohol use were established with traffic accident rates. Most of the elevated risks among subgroups of the population under investigation were found not to be due to cannabis use per se, and only partly to drink driving in itself. As a subgroup, the cannabis users in the study of Fergusson and Horwood (*2001*) were prone to engage in drink driving and other risky/illegal driving practices, associated with attitudes encouraging driving violations. They suggest that these driving behaviours are frequently part of more general tendencies towards risky and unsafe driving, among which is ill-judged decision making on the road (Horwood and Fergusson *2000*). The present study strongly supports their findings, from a different methodological angle.

The present study has some limitations. Firstly, the study was carried out in a driving simulator, for ethical reasons a necessary restriction, but for validity reasons constraining the ecological power. However, we are convinced that this necessary “choice” has been successfully defended in the past (De Waard et al. *1999b*). Secondly, a quasi-experimental design could not be avoided, which brought along diminished experimental control, albeit with a gain in realism. The relevance of the findings in terms of the type of effects is a natural given for science, but also has

practical consequences for policy makers. Any investment in regulating drug (and drink) driving among young people should be accompanied by similar investments in reducing unsafe driving in all other aspects.

Acknowledgement This study was supported financially by the Dutch Ministry of Transport, Transportation Research Centre AVV.

References

Backs RW, Seljos KA (1994) Metabolic and cardiorespiratory measures of mental effort: the effects of level of difficulty in a working memory task. Int J Psychophysiol 16:57–68

Brookhuis KA, De Vries G, Prins van Wijngaarden P, Veenstra, G, Hommes, M, Louwerens, JW, O'Hanlon, JF (1985) The effects of increasing doses of meptazinol (100, 200, 400 mg) and glafenine (200 mg) on driving performance. Traffic Research Centre, University of Groningen, Haren, The Netherlands

Brookhuis KA, Volkerts ER, O'Hanlon JF (1990) Repeated dose effects of lormetazepam and flurazepam upon driving performance. Eur J Clin Pharmacol 39:83–87

Brookhuis KA, De Vries G, De Waard D (1993) Acute and subchronic effects of the H_1-histamine receptor antagonist ebastine in 10, 20 and 30 mg dose, and triprolidine 10 mg on car driving performance. Br J Clin Pharmacol 36:67–70

Brookhuis KA, De Waard D, Mulder LJM (1994) Measuring driving performance by car-following in traffic. Ergonomics 37:427–434

Davison D, Parrott AC (1997) Ecstasy (MDMA) in recreational users: self-reported psychological and physiological effects. Hum Psychopharmacol 12:221–226

De Waard D, Brookhuis KA (2000) Drug effects on driving performance, letter to the editor. Ann Int Med 133:656–657

De Waard D, Van Der Hulst M, Brookhuis KA (1999a) Elderly and young drivers' reaction to an in-car enforcement and tutoring system. Appl Ergonom 30:147–157
crossref

De Waard D, Van der Hulst M, Hoedemaeker M, Brookhuis KA (1999b) Reply to comments on "Driver behavior in an emergency situation in the Automated Highway System". Transport Hum Fact 1:87–89

Fergusson DM, Horwood LJ (2001) Cannabis use and traffic accidents in a birth cohort young adults. Accident Anal Prevent 33:703–711
crossref ChemPort

Horwood LJ, Fergusson DM (2000) Drink driving and traffic accidents in young people. Accident Anal Prevent 32:805–814
crossref ChemPort

Kramer AF (1991) Physiological metrics of mental workload: a review of recent progress. In: Damos DL (ed) Multiple-task performance. Taylor and Francis, London, pp 279–328

Krystal JH, Price LH, Opsahl C, Ricaurte GA, Heninger GR (1992) Chronic 3,4-methylenedioxymethamphetamine (MDMA) use: effects on mood and neuropsychological function? Am J Drug Alcohol Abuse 18:331–341
ChemPort PubMed

Logan BK, Couper FJ (2001) 3,4-Methylenedioxymethamphetamine (MDMA, ecstasy) and driving impairment. J Forens Sci 46:1426–1433
ChemPort

Michon JA (1985) A critical view of driver behavior models: what do we know, what should we do? In: Evans L, Schwing RC (eds) Human behavior and traffic safety. Plenum Press, New York, pp 485–524

Morgan MJ (1998) Recreational use of "ecstasy" (MDMA) is associated with elevated impulsivity. Neuropsychopharmacology 19:252–264
crossref ChemPort PubMed

Morgan MJ (2000) Ecstasy (MDMA): a review of its possible persistent psychological effects. Psychopharmacology 152:230–248
ChemPort PubMed

Mulder LJM (1992) Measurement and analysis methods of heart rate and respiration for use in applied environments. Biol Psychol 34:205–236
PubMed

Mulder LJM, De Waard D., Brookhuis K.A. (2003) Estimating mental effort using heart rate and heart rate variability. In: Stanton N, Hedge A, Hendrick HW, Brookhuis KA, Salas E (eds) Handbook of ergonomics and human factors methods. Taylor and Francis, London

Parrot AC, Larsky J (1998) Ecstasy (MDMA) effects upon mood and cognition: before, during and after a Saturday night dance. Psychopharmacology 139:261–268
SpringerLink ChemPort PubMed

Parrott AC, Stuart M (1997) Ecstasy (MDMA), amphetamine, and LSD: comparative mood profiles in recreational polydrug users. Hum Psychopharmacol 12:501–504
crossref ChemPort

Rodgers J (2000) Cognitive performance amongst recreational users of "ecstasy". Psychopharmacology 151:19–24
ChemPort PubMed

Samyn N, Verstraete A, Van Haeren C, Kintz P (1999) Analysis of drugs of abuse in saliva. Forens Sci Rev 11:1–19

Samyn N, De Boeck G, Wood M, Lamers, CTJ, De Waard, D, Brookhuis, KA, Verstraete, AG, Riedel, WJ (2002) Plasma, oral fluid and sweat wipe ecstasy concentrations in controlled and real life conditions. Forens Sci Int 128:90–97
crossref ChemPort

Schifano F (1995) Dangerous driving and MDMA ("Ecstasy") abuse. J Seroton Res 1:53–57

Van Roon AM (1998) Short-term cardiovascular effects of mental tasks. Physiology, experiments and computer simulation. PhD Thesis, University of Groningen, Groningen, The Netherlands

Van Wolffelaar PC, Van Winsum W (1995) Traffic simulation and driving simulation—an integrated approach. In: Proceedings of the Driving Simulator Conference (DSC '95). Teknea, Toulouse, France

Verkes RJ, Gijsman H, Pieters MSM, Schoemaker RC, De Visser S, Kuijpers M, Pennings EJM, Van Gerven JMA, Cohen AF (2001) Cognitive performance and serotonergic function in users of ecstasy. Psychopharmacology 153:196–202
ChemPort PubMed

Vollenweider FX, Gamma A, Liechti M, Huber T (1998) Psychological and cardiovascular effects and short-term sequelae of MDMA ("ecstasy") in MDMA-naive healthy volunteers. Neuropsychopharmacology 19:241–251
crossref ChemPort PubMed

Zijlstra FRH (1993) Efficiency in work behavior. A design approach for modern tools. PhD thesis, Delft University of Technology, Delft. Delft University Press, The Netherlands.