Psychomotor tremor and proprioceptive control problems in current and former stimulant drug users: an accelerometer study of heavy users of amphetamine, MDMA, and other recreational stimulants.

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Abstract

The recreational use of various stimulant drugs has been implicated in the development of movement disorders through dysregulation of the dopaminergic and serotoninergic neurotransmitter systems. The present study investigated psychomotor differences in current and former recreational stimulant drug users compared to non-using controls. Sixty participants comprised three groups: 20 current stimulant drug users (CSU: 11 males, age= 31.4(9.1)), 20 former stimulant drug users (FSU: 5 males, age= 39.1(8.5)), and 20 non-user controls (NUC: 5 males, age= 35.7(16.4)). Psychomotor arm steadiness for each participant was assessed with a wrist-attached accelerometer during five arm positions with eyes open and then eyes closed. Arm-drop of arm position was indicated by the Arm Longitudinal Rotation Axis (ALoRA), and tremor was indicated by the overall Vector of Dynamic Body Acceleration (VeDBA). Overall, CSU performed the most poorly on ALoRA ($p < 0.05$) and VeDBA indices ($p < 0.05$), and FSU perform almost as poorly on VeDBA indices ($p < 0.05$), compared to NUC. It was concluded that stimulant drug use, primarily MDMA and amphetamine, may result in acute stimulant-induced tremor as well as long-term proprioceptive deficits in terms of arm-droop.

Keywords: accelerometry, MDMA, ecstasy, amphetamine, psychomotor, tremor, abstinence

Introduction

Consumption of recreational drugs has been implicated in the development of movement disorders such as akathisia, ataxia, dyskinesia and motor tremor[1,2] by disrupting the dopamine and serotonin neurotransmitter systems[3-10]. Since the symptoms associated with these various movement disorders can appear acutely (whilst on drug), sub-acutely (days or weeks after drug ingestion), or tardively (months or years after initial exposure to drug) following regular or repetitive exposure[11,12], they can have a significant impact on users' quality of life.

Several studies have shown that immediately after ingesting the synthetic, psychoactive drug 3,4-methylenedioxymethamphetamine (MDMA), participants describe acute side effects including motor tics, twitches, tremors, shakes, muscular pain, unconscious arm movements, numbness and tingling sensations[10,13,14]. In an Internet survey of 282 recreational MDMA users, 14% of novice users (1-9 lifetime occasions), 20% of moderate users (10-99 lifetime occasions) and 38% of experienced users (+100 lifetime occasions) reported increased tremors and/or twitches[15]. In a study of children whose mothers used MDMA during their first trimester of pregnancy, there were significant psychomotor delays at 4- and 12-months post-partum[16]. The potential causative factors may include both neurotransmitters and neurohormones, since recreational MDMA has also been shown to increase levels of the stress hormone cortisol[17].

Using accelerometry, stimulant drug users' current micro- and macro-movement abilities can be assessed[18-20], which in turn allows for the investigation of movement abnormalities as a potential marker of motor circuitry abnormalities and the later development of movement disorder[20]. Empirical research investigating the effect of stimulants on motor

function using accelerometry is limited. We have previously used accelerometry to identify micro-movements related to caffeine withdrawal and caffeine consumption[21]. Further, we have presented evidence of marked differences in psychomotor control – specifically 'tremor' values (vectorial dynamic acceleration[19]) – in MDMA users when they hold their arms horizontally[18].

Flavel, Koch, White, Todd [20] measured the degree of finger tremor for abstinent amphetamine, MDMA and cannabis users compared to non-drug users and observed significant impairment in MDMA users. Todd, Flavel, Koch, White [22] compared index finger motion and tremor during rest and movement between abstinent MDMA users, abstinent methamphetamine users, abstinent cannabis users, and non-user controls. Using accelerometry, the authors noted that only abstinent MDMA users displayed abnormally large motion tremors during movement compared to abstinent methamphetamine users, abstinent cannabis users and non-user controls. Bauer [23] report increasing resting hand tremor for cocaine users following 12 weeks of abstinence, while the resting hand tremor of alcohol users reduced over the 12-week period. The authors suggest that these results may be indicative of extrapyramidal dysfunction in cocaine users. Finally, following one year of cocaine and/or amphetamine abstinence, motor skills were more impaired for past users compared to their non-using twin[24].

The aim of the present study was to investigate the potentially harmful sub-acute and chronic effects of heavy stimulant drug use on psychomotor control. Based on previous research we hypothesized that deficits in psychomotor control, specifically arm-droop and tremor, would be greater for current and former stimulant drug users compared to non-users,

and that these deficits would be enduring, with no difference in arm-droop and tremor expected between current and former drug using groups.

Materials and Methods

Ethics Statement

The ethics committee of the Department of Psychology at Swansea University approved the between-subject study design in accordance with the Declaration of Helsinki and all participants provided written informed consent.

Participants

Sixty participants who were not undertaking nor seeking any medical treatment and were free from any neurological condition volunteered for this study. There were three experimental groups: current stimulant users (CSU: *N*= 20, males= 11, age= 18-45, *M*(*SD)*= 31.4(9.1)), former stimulant users (FSU: *N*= 20, males= 5, age= 20-55, *M*(*SD)*= 39.1(8.5)) and non-user controls (NUC: *N*= 20, males= 5, age= 18-63, *M*(*SD*)= 35.7(16.4)).

The inclusion criteria for the CSU and FSU groups were that they used at least one of four recreational stimulant drugs (amphetamine, MDMA, cocaine or mephedrone) at least twice per week for a minimum of two years. The FSU group were also required to have been abstinent from stimulants for at least 18 months prior to the study. It should be noted that participants were poly-drug users, and many reported having taken MDMA (around 50%) and/or amphetamine (around 85%) intravenously. To our knowledge, intravenous poly-drug use has not been empirically investigated previously. The inclusion criterion for the NUC was

of no history of illicit drug use. Tobacco smoking was allowed to prevent any nicotine withdrawal symptoms affecting the results.

Experimental Protocol

All participants completed the University of East London Recreational Drug Use Questionnaire to quantify lifetime drug usage[25]; drug usage characteristics of the three groups are shown in Table 1. All participants wore an X6-2A USB accelerometer (Gulf Coast Data Concepts, LLC, Waveland, USA) attached in a standardized manner to the dorsal surface of the wrist of their dominant hand (Figure 1a). The device recorded acceleration in three orthogonal axes X, Y and Z (also termed sway, surge and heave, respectively, Figure 1a) at 80 Hz with a resolution of 16-bit and a recording range of ±6.0 *g* (acceleration of gravity). The participants were then asked to hold their dominant arm in one of 10 positions (all horizontal, perpendicular to the body), one at a time, and maintain the position for 60 seconds at each position. Participants were given a 30-second rest between each arm position. The arm positions were carried out in the following order:

- Position 1. Sitting upright on a chair, both arms extended forward and parallel to each other.
- Position 2. Remaining seated, extending arms to the sides.
- Position 3 and 4. Position 1 and 2 repeated while standing upright.
- Position 5. Standing upright, only dominant hand extended forward holding a pen between index finger and thumb.
- Position 6 to 10. Position 1 to 5 repeated with eyes closed.

See Figure 1b for an example of the raw accelerometry data of a single NUC participant during position 1.

Data Analysis

Accelerometry data was first smoothed with a running mean over 2 seconds for each of the three axes (x, y, z). This method of smoothing resulted in the 'static' or gravity-based component of acceleration, which was an indication of the posture of the arm in relation to the horizon[26]. The 'dynamic' acceleration, or muscular activity, of the participant's arm was calculated by subtracting the static acceleration from the raw acceleration values (cf.[19]). The Vector of Dynamic Body Acceleration (VeDBA), which was representative of all 3-dimensional motion made by the participants, was then calculated by taking the square root of the added squares of the dynamic acceleration data from the three axes (x, y and z; cf.[27]). VeDBA therefore provided a measure of participants' arm tremor. The motion detected on the y-axis only (Arm Longitudinal Rotation Axis; ALoRA), represented the extent to which the participant's arm-droops while attempting to maintain steady arms in front of the body (see Figure 1a).

Statistical Analysis

Descriptive statistics of the ALoRA and VeDBA axes were calculated for each participant and later converted from standard acceleration of gravity (*g*) to degrees (°) for a clearer indication of arm motion; a value of 0° indicated a perfectly horizontal position. The grand mean interquartile range (IQR) was then calculated for each group. Four multivariate analyses of variance (MANOVA) were conducted to investigate group differences in IQR for ALoRA and VeDBA in eyes open and eyes closed conditions separately. Experimental group differences in age, sex and lifetime drug use were analysed using analysis of variance

(ANOVA) for continuous variables, and chi-square for categorical variables. Kruskal-Wallis H tests were used where the assumptions of an ANOVA were not met. All statistics were carried out using SPSS version 22[28].

Results

Demographic Differences

A one-way ANOVA revealed no differences between the three groups in age (*M*(*SD*): NDT= 35.7(16.0), CSU= 31.4(8.9), FSU= 39.1(8.3); $F(2, 57)= 2.13$, $p= 0.128$), and a chi-square test observed no significant group difference in sex ratio ($X^2(2)= 5.28$, $p= 0.072$). A two-way (group x drug) ANOVA investigating the differences in lifetime stimulant usage between the CSU and FSU groups revealed no significant difference between the groups on overall lifetime drug use ($F(1, 494)= 0.137$, $p= 0.711$), however, there was a significant difference in lifetime use between the type of drug used, with amphetamines and MDMA far more commonly used than the other drug types (see Table 1). There was no group by drug interaction, suggesting the groups did not differ in their use of specific drug types significant ($F(12, 494)= 0.27$, $p= 0.995$).

A Kruskal-Wallis H test showed that there was a significant difference between the three groups in their use of tobacco ($H(2)= 17.75$, $p < 0.001$) and cannabis ($H(2)= 11.37$, $p= 0.003$). This difference was driven by the NUC group containing only two smoking and no cannabis-using participant; there was no difference between CSU and FSU groups consumption of tobacco ($X^2(1)= 0.100$, $p= 0.752$) or cannabis ($X^2(1)= 1.758$, $p= 0.185$). There was no significant difference between the three groups in alcohol consumption ($X^2(2)= 1.200$, $p= 0.549$).

Accelerometry Differences

The comparative psychomotor performance of the three groups can be seen in Table 2. Overall, there were widespread differences between the groups for both ALoRA (arm-droop) and VeDBA (tremor) measures. The CSU group had the highest mean acceleration angle scores with largest standard deviation values, followed by the FSU group and then the NUC group.

ALoRA IQR results from positions 1 to 5 (eyes open) show that both stimulant using groups 'droop' their arms below horizontal more than the NUC group, and the MANOVA demonstrated this difference was significant with a significant main effect for group (F(10, 108)= 1.98, $p < 0.05$; Pillai's Trace= 0.309, η^2= 0.16). *Post-hoc* analyses revealed that the group difference was driven by increased ALoRA for positions 3 (F(2, 57)= 3.88, $p < 0.05$; η^2= 0.12) and 4 (F(2, 57)= 4.29, $p < 0.05$; η^2= 0.13), and a trend for position 5; (F(2, 57)= 3.03, p= 0.056; η^2= 0.10). The MANOVA of ALoRA IQRs for the eyes-closed arm positions (i.e., positions 6 to 10) again indicated a significant main effect for group (F(10, 108)= 2.03, $p < 0.05$; Pillai's Trace= 0.317, η^2= 0.16). *Post-hoc* analyses revealed significant increase in ALoRA for the stimulus using groups in positions 6 (F(2, 57)= 4.59, $p < 0.05$; η^2= 0.14), 7 (F(2, 57)= 4.90, $p < 0.05$; η^2= 0.15), and 9 (F(2, 57)= 3.46, $p < 0.05$; η^2= 0.11), and reduced ALoRA for the FSU group for position 10 (F(2, 57)= 3.47, $p < 0.05$; η^2= 0.11). Tukey HSD *post-hoc* group comparisons revealed significant differences between NUC and CSU for positions for positions 3, 4, 6, 7 and 9, and between CSU and FSU for positions 4 and 10; these comparisons are presented in Table 2.

More striking were the differences in tremor as represented by the VeDBA axis of

each of the 10 positions. The CSU and FSU VeDBA scores were higher during each position of the eyes-open condition, indicating more tremor, and the MANOVA indicated this difference between groups to be significant ($F(10, 108)= 4.46$, $p < 0.001$; Pillai's Trace= 0.585, $\eta^2= 0.29$). *Post-hoc* analyses revealed the increase to be driven by significant differences for each of the five positions; position 1 ($F(2, 57)= 18.80$, $p < 0.001$; $\eta^2= 0.40$), 2 ($F(2, 57)= 12.16$, $p < 0.001$; $\eta^2= 0.30$), 3 ($F(2, 57)= 6.91$, $p < 0.01$; $\eta^2= 0.20$), 4 ($F(2, 57)= 7.65$, $p < 0.01$; $\eta^2= 0.21$), and 5; ($F(2, 57)= 6.73$, $p < 0.01$; $\eta^2= 0.19$). VeDBA scores were also greater for each of the five positions during the eyes-closed condition; the MANOVA indicated the increase was significant ($F(10, 108)= 2.53$, $p < 0.01$; Pillai's Trace= 0.379, $\eta^2= 0.19$). *Post-hoc* analyses revealed the significant group main effect to be driven by significant differences at each of the five positions; 6 ($F(2, 57)= 6.83$, $p < 0.01$; $\eta^2= 0.19$), 7 ($F(2, 57)= 11.93$, $p < 0.001$; $\eta^2= 0.30$), 8 ($F(2, 57)= 7.07$, $p < 0.01$; $\eta^2= 0.20$), 9 ($F(2, 57)= 6.13$, $p < 0.01$; $\eta^2= 0.18$), and 10 ($F(2, 57)= 8.89$, $p < 0.001$; $\eta^2= 0.24$). Overall VeDBA for all 10 positions was significantly larger for CSUs than NUCs, whilst VeDBA for positions 1, 2, 3, 5, 6, 7 was lager for FSUs than for NUCs, and only VeDBA in position 1 was significantly different between CSU and FSU. The Tukey HSD comparisons for positions 1 to 10 are presented in Table 2.

Discussion

This study observed significant psychomotor control deficits in current and former recreational users of stimulant drugs compared to non-user controls. As predicted, tremor (VeDBA) was larger for current users compared to non-users for each of the ten positions. Former users also demonstrated larger tremor than non-users, however, the increase was only statistically significant for six of the ten positions (four with eyes open and two with eyes

closed). There were fewer arm-droop (ALoRA) deficits observed for current users, while no significant deficits were observed for the former users compared to non-users. Finally, as predicted, tremor and arm-droop did not differ between current and former users, except in three of the 20 positions where there was increased deficit for current users: VeDBA in the first position, ALoRA in the fourth position and ALoRA in the tenth position. Overall, these findings indicate impairments in both tremor and arm-droop in heavy stimulant users, and that tremor, but not arm-droop, persists for at least 18 months following withdrawal from stimulant use.

These data suggest that the effect of stimulant use on tremor endures for over 18 months of abstinence, with all but one position eliciting a similarly high degree of tremor between current and former stimulant users. These findings are somewhat supported by research reporting enduring tremor after a 12-week washout of cocaine, which was suggested to indicate extrapyramidal dysfunction in these users[23]. Former users displayed less tremor than current users for the first position of this study, and tremor was comparable between former and non-users for four of the ten positions, suggesting some degree of recovery from the acute effects of stimulant drug use over 18 months of abstinence.

In terms of arm-droop, results suggest poorer proprioceptive functionality for current users compared to non-users for most positions, and compared to former users for two positions. Unlike tremor, proprioception appears to improve over time, with no significant differences in arm-droop between former users and non-users. These findings suggest that stimulant users recover their proprioceptive capacity over a period of time of abstinence.

Deficits in motor dexterity and speed have been reported to continue for former stimulant users following one year of abstinence, however, these were within normal limits[24].

Psychomotor deficits can lead to a range of adverse implications for everyday tasks, including social functioning, interpersonal communication, and performance on simple and complex motor tasks, and the detection of psychomotor deficiencies might be considered an early marker for movement disorders[29]. These outcomes pose significant health and safety risks for stimulant drug users[30,31], highlighting the need for better management of prevention and recovery programs for stimulant drug use.

The current findings are broadly consistent with previous research suggesting that stimulant drug use leads to tremor and psychomotor movement abnormalities through their effect on dopaminergic and serotonergic pathways (i.e., stimulants)[1,3,20,29,32, Parrott, 2013 #549]. For example, the acute effects of MDMA have been shown to include tics, twitches, tremors and shakes[13,14,]. Furthermore, 38% of heavy MDMA users report psychomotor problems, which they attribute to MDMA use[15,33].

Although arm droop and tremor differences between current, former and non-drug users were observed in this study, it is unclear whether these directly predict the degree of movement deficit in clinical populations as no studies to date employ ALoRA and VeDBA as measurement indices. Work by Flavel, Koch, White, Todd [20] suggests that increased tremor might mark motor abnormalities and the future development of movement disorders, as stimulant use has been associated with later diagnosis of conditions such as tics, dystonia and essential tremor. Wilson, Grundy, Massy, Soltis, Tysse, Holton, Cai, Parrott, Downey, Qasem, Butt [18] suggests that abnormalities in micro-movements may index later development of movement disorder in non-clinical populations, as MDMA has been associated with aberrant serotonin transportation, and serotonergic disruption has been associated with movement disorder[9].

Differences observed between the eyes-open and eyes-closed tasks may be attributed to motion perception ability. The physiological control of body position and movement involves multiple neural processes, requiring visual and proprioceptive cues[34]. In the eyes-closed condition, visual cues are removed, increasing the load on proprioceptive function, suggesting that a higher degree of arm movement is associated with a proprioceptive deficit. Therefore, this study suggests sub-acute proprioceptive deficits for stimulant users that appear to improve over time for some positions.

There are some limitations of this study that require mention. First, cannabis and tobacco (nicotine) consumption differed between the experimental groups. Cannabis use has been suggested to reduce serotonin neurotoxicity, thus ameliorate the effects of MDMA on pathways involved in psychomotor movement[10,35]. Current users were shown to consume more cannabis than former users, who in turn consumed more than non-users, thus it is possible that the psychomotor differences between the groups may have been larger in the absence of cannabis use. It should be noted, however, that the ratio of cannabadiol and THC in cannabis is highly variable, and as such the extent that recreational cannabis might reduce neurotoxicity remains unknown. Nicotine consumption was higher for both stimulant user groups compared to non-users, and nicotine has been shown to enhance the locomotor effects of amphetamines and dopamine pathways in rats[36]. It is therefore possible that nicotine differences between the stimulant using and non-using groups is exacerbated by nicotine consumption. Second, participants within the stimulant user groups were typically poly-drug users, which is common among the general user population[7,37]. Parrot et al., (2017, in press) suggests that poly-drug use is a significant problem for research into the effects of recreational drugs, it is therefore difficult to ascribe the findings of psychomotor deficit to any

one particular drug[38]. Third, we relied on self-report stimulant use and did not test compliance of abstinence with blood or urine samples. It is possible that some participants were affected by stimulants at the time of the study, which may have resulted in increased tremor [10]. Finally, the age difference between current and former users was substantial; the ratio of females to males was 2.5:1 for former users and non-users, and there was an 8-year mean age difference between current and former stimulant users. There are no studies investigating sex and age differences in VeDBA and ALoRA measure, however, it is unlikely tremor and arm-droop would be significantly impacted across the 10-year age-span. Nevertheless, these data demonstrate psychomotor characteristics that are present in the non-clinical drug using community, and are thus an important contribution to the literature at large.

In conclusion, this study used accelerometry to demonstrate significant psychomotor deficits for current users of recreational stimulant drugs. These deficits appear to persist for at least 18 months following cessation of stimulant drug taking. The physical effects of stimulant drugs might manifest from serotonin and dopamine pathway disruption caused by the drugs, however, there appears to be a degree of recovery, with former users performing better than their current user counterparts on a number of psychomotor positions. Having detected a degree of recovery for former users, accelerometer devices have the potential to become an important predictor of adverse effects that may lead to long-term psychological and psychomotor damage. In this way, metrics such as tremor and arm-droop could be used as valid risk markers for the development of movement disorders.

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Table 1: Percentage and *mean*(*SD*) use of drugs for each experimental group

	Percent users(%)			Average usage(*mean*(*SD*))		
	NUC	CDU	FDU	NUC	CDU	FDU
MDMA	0	85	90	0(0)	276.4(335.1)	350.9(330.2)
MDMA(IV)	0	65	50	0(0)	0.6(0.4)	0.5(0.5)
Amphetamine	0	90	100	0(0)	565(412.6)	532.4(325.7)
Amphetamine(IV)	0	85	95	0(0)	0.8(0.3)	0.9(0.2)
Cocaine(nasal)	0	60	65	0(0)	36.7(107.3)	36.7(51.3)
Cocaine(IV)	0	35	35	0(0)	0.3(0.4)	0.3(0.4)
Cocaine(crack)	0	40	25	0(0)	5.6(12.2)	9.5(23.9)
Crack(IV)	0	0	5	0(0)	0(0)	0(0)
LSD	0	30	35	0(0)	1.3(2.8)	9(23.3)
LSD(IV)	0	0	5	0(0)	0(0)	0(0)
Mephedrone	0	45	25	0(0)	2.3(3.2)	3.2(7.6)
Mephedrone(IV)	0	15	10	0(0)	0.1(0.3)	0.1(0.3)
Opiates	5	10	5	0.1(0.4)	0.2(0.6)	0.2(1)
Opiates(IV)	5	0	0	0(0)	0(0)	0(0)
Benzodiazepines	0	0	10	0(0)	0(0)	1(3)
Benzodiazepines(IV)	0	0	5	0(0)	0(0)	0(0)
Magic mushrooms	0	40	20	0(0)	1.6(4.3)	6.1(21.9)
Magic mushrooms(IV)	0	0	5	0(0)	0(0)	0(0)
Anabolic steroids	0	0	0	0(0)	0(0)	0(0)
Anabolic steroids(IV)	0	0	0	0(0)	0(0)	0(0)
Solvents	0	15	15	0(0)	0.9(2.7)	0.8(2.3)
Solvents(IV)	0	0	5	0(0)	0(0)	0(0)
Poppers	0	30	40	0(0)	11.5(43.4)	12.7(24.2)
Poppers(IV)	0	0	5	0(0)	0(0)	0(0)
Ketamine	0	15	15	0(0)	0.2(0.5)	0.2(0.6)
Ketamine(IV)	0	0	10	0(0)	0(0)	0(0.2)
Tobacco	10	70	65	0.7(2.3)	5.2(4.2)	4.6(4.6)
Alcohol	65	65	65	3.1(3.4)	3.7(3.8)	4.8(3.8)
Cannabis	0	45	25	0(0)	3.7(5.3)	1.5(2.8)

Note: NUC = non-user controls, CSU = current stimulant users, FSU = former stimulant users, MDMA = 3,4-methylenedioxymethamphetamine, LSD = Lysergic acid diethylamide, IV = intravenous. Averages for stimulant drugs are lifetime use, tobacco is cigarettes per day, alcohol is units per week, and cannabis is use per month.

Table 2. *Mean*(*SD*) interquartile ranges in degrees (°) of the two motion axes, Arm Longitudinal Rotation Axis (ALoRA) and Vector of Dynamic Body Acceleration (VeDBA) during the 10 different arm activities.

Activity	NUC	CSU	FSU
ALoRA eyes open			
1	2.37(1.52)	2.52(1.53)	2.85(1.53)
2	3.36(1.80)	3.30(1.91)	3.04(1.47)
3	2.35(1.56)	3.91(2.27) *	2.72(1.64)
4	2.87(1.66)	4.22(2.26) *#	2.73(1.29)
5	1.95(1.57)	3.27(2.27)	3.09(1.59)
ALoRA eyes closed			
6	2.27(1.92)	4.14(2.59) *	2.74(1.41)
7	2.64(1.52)	6.45(6.37) *	3.81(1.96)
8	2.59(1.70)	3.50(2.23)	3.64(2.84)
9	2.96(1.77)	4.40(1.74) *	3.51(1.74)
10	3.55(2.66)	4.74(2.39) #	2.93(1.32)
VeDBA eyes open			
1	0.34(.11)	0.79(.32) *#	0.57(.20) *
2	0.36(.11)	1.04(.66) *	0.78(.37) *
3	0.38(.12)	0.91(.68) *	0.74(.38) *
4	0.45(.18)	1.17(.92) *	0.74(.40)
5	0.44(.22)	0.82(.40) *	0.79(.65) *
VeDBA eyes closed			
6	0.56(.28)	0.93(.29) *	0.82(.40) *
7	0.43(.14)	1.01(.51) *	0.81(.39) *
8	0.49(.19)	0.88(.45) *	0.67(.29)
9	0.49(.17)	1.15(.94) *	0.76(.41)
10	0.42(.19)	0.92(.51) *	0.70(.34)

Note: CSU = current stimulant users, FSU = former stimulant users, NUC = non-user controls. * = significantly different from NUC, # = significantly different from FSU.

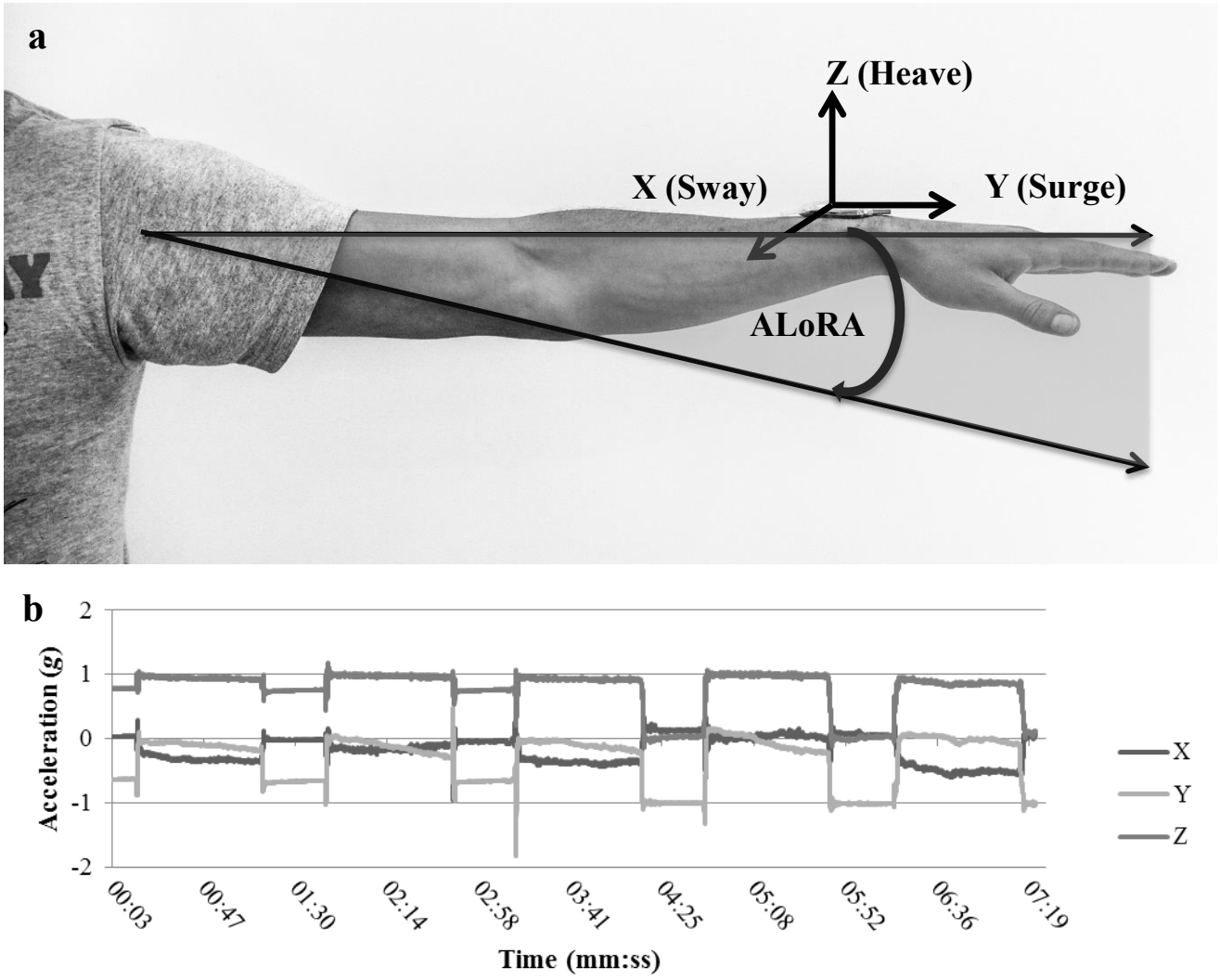

Figure 1. **a**) Position of the accelerometer device and its three orthogonal axes X, Y and Z (which measure sway, surge and heave motions respectively) as attached to the wrist of the subject's dominant hand. The Arm Longitudinal Rotation Axis (ALoRA) is denoted by the Y-axis and records arm steadiness. This is measured as the change in arm position as it deviates from horizontality of 0° or in other words, the degree of 'arm-drop'. The more the participant deviates from an arm position of 0°, the more it implies psychomotor difficulties. **b)** Example of the raw accelerometry signal as seen in axes X, Y and Z, showing activities 1 to 5 as carried out (with eyes open) by a non-user participant. Looking at the Y-axis, the signal can be seen 'dropping' during the five activities, indicating a normal level of arm-drop due to muscle fatigue (these levels were much more pronounced for both current and former stimulant users).