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Circadian Clock and Subjective Time Perception: A Simple Open Source Application for the Analysis of Induced Time Perception in Humans

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Abstract**—**Subjective time perception implies connection to cognitive functions, attention, memory and awareness, but a little is known about connections with homeostatic states of the body coordinated by circadian clock. In this paper, we present results from experimental study of subjective time perception in volunteers performing physical activity on treadmill in various phases of their circadian rhythms. Subjects were exposed to several time illusions simulated by programmed timing systems. This study brings better understanding for further improvement of of work quality in isolated areas.

Keywords**—**Biological clock, light, time illusions, treadmill.

I. Introduction

BIOLOGICAL clock evolved in living creatures as an adaptation to day and night cycles caused by rotation of the Earth. It synchronizes organisms, particularly their metabolic rhythms to environmental stimuli such as light, food or temperature [1]. Light stimuli originated from stars seem to play particular role not only in biological clock entrainment but also in environmental adaptations helping organisms in spatial orientation, navigation, hunting behaviors and time perception. For example, Sun's position on the sky can suggest when prey drinks water from a river, or when nectar is replenished from a blooming plant. But time perception is not only an adaptation of central nervous system to diverse temporal events associated with environmental changes. It also relates to intrinsic cognitive processes [2], making this neural mechanism far more complex than what we define as biological clock. In fact, very little is known about connection between biological clock and time perception systems. Experimental data revealed that living in isolation from clocks and natural light elongates both subjective time perception and circadian rhythms, indicating a connection between these two timing systems [3].

Several studies relate time perception with emotional states, levels of attention, memory and diseases [2]. Time processing regions are located in frontal cortex, basal ganglia, parietal cortex, cerebellum and hippocampus. The main neurotransmitters involved in time perception are dopamine (related with perception of seconds and minutes in frontostriatal circuitry) [3], [4] and acetylcholine (related to memory and attention in frontal cortex and parietal regions) [5]. Drugs alter time perception by affecting the speed of internal clock and the amount of attention paid to time [6]. During sleep, subjective time perception is disturbed similarly to drugs such LSD [7], marihuana [8], and amphetamine [9]. Particular effect on time perception has been observed for alcohol [10], heroin [11], Ecstasy [12], cocaine [13] and nicotine [14]. Cocaine, methamphetamine and alcohol seem to make time speed up, whereas haloperidol and marijuana appear to slow down the time [6]. In general, stimulants make overestimates of time duration, whereas depressants and anesthetics make underestimates of time duration [10], [15], [16].

Time perception is integral to human motivation [17]. The principal advantage of relating time perception to biological clock is the durability of biological clock cycles, jet lags and social jet lags. Disturbed time perception caused by disturbed biological clock could bring obvious problems such as being late for important meetings, deadlines and travels.

Literature concerning the impact of biological clock on time perception is equally scarce. Thus, the aim of this study was to investigate the biological clock effect on subjective time perception. We focused mainly on working hours to get knowledge for improved scheduling of future long-term human spaceflight missions. This paper introduces an open-source tool to measure subjective time perception, available for future global data collection and analysis.

II. Materials and Methods

Four volunteers participated in the experiment: one woman (age 35) and three men (age 24, 24, 29), with regular 7 h sleep and 17 h activity cycles. Selected group was punctual, often using watches and clocks on computers and smartphones, synchronized with global UTC system. Experiment was divided into two phases (Fig. 1). During the first phase individuals were monitored in 4 consecutive days for induced subjective time perception by specially designed STPA (Subjective Time Perception Analysis) software. Computer task was followed by thinking and reasoning test in a form of Sudoku puzzle [18]. At the end, volunteers were asked to estimate time of solving Sudoku test. The main objective of the monitoring phase was observation and visualisation of individual subjective time perception patterns. All participants were told to sleep 8 hours per day starting from 22:00 UTC

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and wake up using alarm clock at 06:00 UTC starting 2 days before the experiment. Sleep hours were denoted individually by each participant.

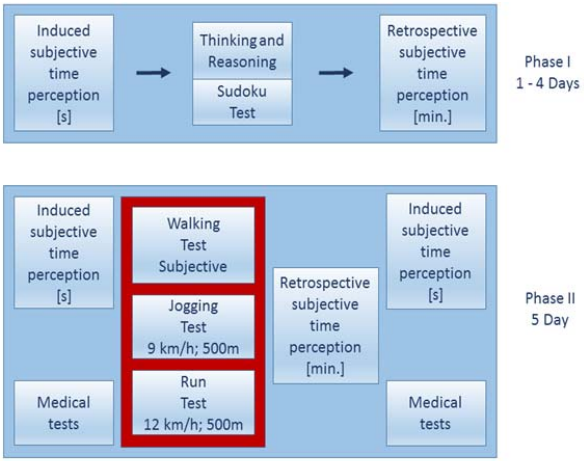


Fig. 1 The scheme of experiment design for testing induced and retrospective subjective time perception: 4-days long monitoring phase I was followed by phase II with additional treadmill tests (dark box). Before and after the treadmill tests, induced subjective time perception was analyzed and medical data were collected

Subjects were coffee deprived during the whole week of the testing phase. Three time points have been set for data collection and analysis: in the morning around 9:00, after lunch around 12.00 and afternoon around 15.00. 3 h intervals were selected in order to get the overall view of subjective time perception during working hours.

The second phase of experiment replaced Sudoku test by physical activity exercises using Club Series Treadmill (Life Fitness) and Neuroon mask (Inteliclinic, www.neuroon.com). The mask provided white led light during the training and isolated from external visual stimuli. The main objective of this phase was to analyse the effect of increased metabolism after physical activities on subjective time perception. Individuals were asked to run STPA test before and after the treadmill task. Additionally, basic physiological parameters such as body temperature, pulse, blood pressure and oxygen saturation were measured using commercially available non-invasive electronic devices: iHealth wireless blood pressure monitor BP5 (Andon Health), iHealth wireless pulse oximeter PO3M (Andon Health), and thermometer (Pic Solution). Continuous measurements of heart rate were obtained by TomTom Runner 2 Cardio watch. 12 different easy Sudoku puzzles were selected from internet and randomly distributed among four days (three puzzles per day, same Sudoku for each person per trial). Subjects had a minor experience in solving Sudoku tests before the experiment. Solving a puzzle was proceeded by STPA test (Fig. 2) and repeated three times per day with 3 h interval brakes. During the brakes individuals performed daily work duties and eaten regular meals.

A. Treadmill Behavioral Tests

Physical activities were divided into 3 main tasks. Just after collecting medical data, a subject was asked to wear a heart rate measuring watch, approach the treadmill and cover eyes with the mask.

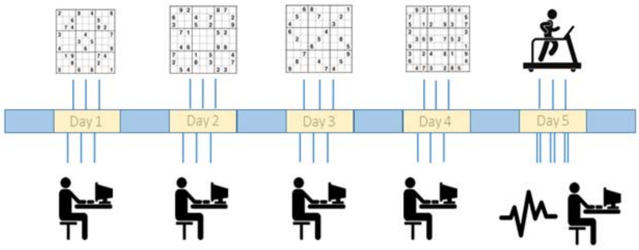


Fig. 2 Timeline of the experiment: Light and dark boxes refer to days and nights (17 h of activity, 7 h of sleep, not in scale to simplify the graphics). Blue lines refer to tasks. During first 4 days each person had to perform 6 tasks per day in a rhythmic manner: in the morning, at noon and afternoon. On the fifth day Sudoku test was replaced with a treadmill activities: walking, jogging and run. Before and just after treadmill task, STPA test together with medical examination were performed

All treadmill tasks were controlled by two assistants: One assistant conducting the experimental procedure, second assistant controlling accuracy of the procedure and taking care of the subject's safety. The first treadmill task was to imagine and perform optimal walking tempo. Subject didn't see the treadmill's display of speed, time and distance values. Assistant was adjusting the speed manually on the machine after subject's suggestions: "faster" or "slower". After approval, individual's walking speed was denoted. Second and third treadmill tasks were set for all individuals equally. Jogging task was defined by speed 9 km/h. After 0.5 km subjects were asked to estimate time of the performed task. The last, ran task, was defined by speed 12 km/h. Again, after 0.5 km subjects were asked to estimate the time of performed task.

B. Software for Time Perception Analysis

Subjective Time Perception Analyzer (STPA) [19] was written as a web application platform. Application was meant to be used both online and offline hence the architecture of this solution is in the client-server model. Client part (frontend) was written in JavaScript with *jQuery* library to handle AJAX requests. Server (backend) was written in Python using Django framework. Both frontend and backend can be used separately and are deployed independently.

Client Side - Experiment and Data Collection

Application was designed to be executed both in controlled experiment environment and on public events like open days, conferences, etc. This requirement had a strong impact on application architecture. Frontend part runs locally on guest web browser henceforth it can be run simultaneously on theoretically unlimited number of devices. The main idea behind the application was to be able to run experiments offline and afterwards collect data for further analysis.

Frontend part of the application allows users to fill survey and measure clicks on the screen while displaying set of colors (white, blue, red) in randomized order for preset length in seconds. After the experiment, data are uploaded to remote server. Application validates user input to the survey. This functionality was implemented using HTML5 input type validation. Client application randomizes experiment color order. Fisher-Yates (also known as Knuth) shuffle algorithm was used to provide unbiased shuffle results [20], [21].

Server Side - Database and Data Analytics

Backend layer is responsible for data validation and analysis. It provides users with easy to use administration panel with search capability. The administration panel is bundled with request logging viewer module (Fig. 3).

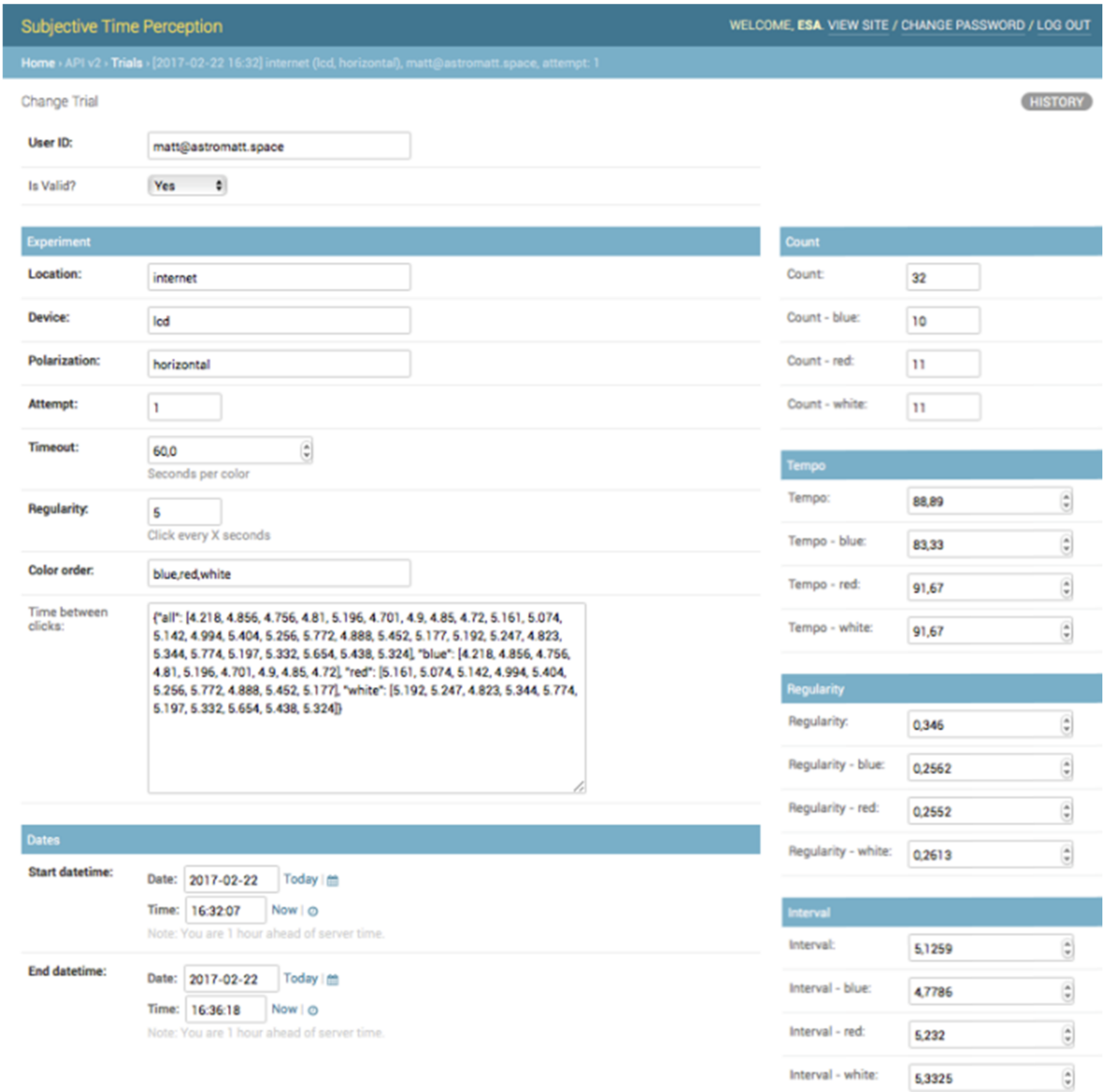


Fig 3 Administration panel of Trial edit screen in the STPA software.

Data analysis is based on temporal click processing method to compute subsequent output parameters:

1. Counts - number of clicks per trial;
2. Tempo - percentage of clicks per trial. Tempo 100% defines value 100% precise with physical time and equals 12 clicks with 5 s intervals within 1 min. for single color trial;
3. Interval - mean average of intervals between clicks from single trial;
4. Regularity coefficient - standard deviation from interval averages. If regularity coefficient goes to 0, regularity increases;

For intervals and regularity coefficients, first two clicks were removed from analysis to reduce errors related with distraction caused by starting the experiment.

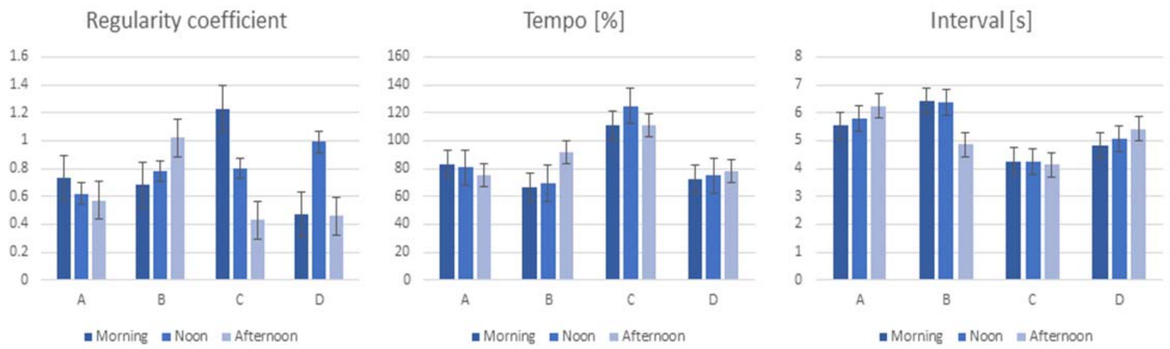
`Python` language with `Django` framework was used to provide easy to develop web applications for running the experiment at global internet scale. The software will be targeting for different platforms such as tablets, `*PC*`, `*Mac*`, smartphones and some custom made setup with LED lamp equipped blindfold. Application backend allows researchers to import and export data in various formats such as: `*.xlsx*`, `*.csv*` and others.

III. Results

A. Induced and Retrospective Subjective Time Perception during Day Times

Counting seconds is not a common state of mental activities for humans; therefore, subjects had to focus on the task in order to perform it correctly. We assumed that counting seconds may be connected with the internal temporal systems linked with biological clock and visual stimuli. Application of STPA software revealed interesting dynamics in induced subjective time perception. Putative biological clock-related differences were mostly observed in regularity of clicking (Fig. 4); however, no general pattern was seen. Other measured parameters such as tempo and clicking intervals seemed to correspond more with personal differences in rhythm sensitivity than with circadian rhythms. Detected changes were quite stable with tendency to elongate comparing to the physical time.

Three participants revealed approximately 20% slower tempo of clicking with subjective 5 second interval reaching up till 6.78 s of physical time duration. One volunteer exhibited opposite effect being 1 s faster than physical time (4 s instead of 5).



Regularity	A	B	C	D
Morning	0.73	0.68	1.23	0.47
Noon	0.62	0.78	0.83	0.99
Afternoon	0.57	1.02	0.43	0.46
Morning	0.87	0.46	0.44	1.04
Noon	0.65	0.47	0.3	1.21
Afternoon	0.55	0.33	0.1	0.34
Morning	0.56	0.65	2.02	0.31
Noon	0.62	0.94	0.12	0.62
Afternoon	0.42	0.57	0.62	0.27
Morning	0.48	0.79	0.2	0.22
Noon	0.38	0.67	1.2	0.37
Afternoon	0.29	0.96	0.3	0.32

Tempo [%]	A	B	C	D
Morning	83.33	66.67	111.11	72.22
Noon	80.56	69.44	125	75
Afternoon	75	91.67	111.11	77.78
Morning	91.67	66.67	125	33.33
Noon	75	75	108.33	66.67
Afternoon	66.67	75	108.33	83.33
Morning	75	66.67	108.33	100
Noon	83.33	66.67	150	75
Afternoon	83.33	91.67	116.67	75
Morning	83.33	66.67	100	83.33
Noon	83.33	66.67	116.67	83.33
Afternoon	75	108.33	108.33	75

Interval [s]	A	B	C	D
Morning	5.53	6.43	4.26	4.82
Noon	5.77	6.36	4.23	5.07
Afternoon	6.25	4.85	4.13	5.42
Morning	5.15	6.63	3.75	5.29
Noon	6.22	5.91	4.28	4.09
Afternoon	6.78	5.88	4.37	5.01
Morning	5.95	6.04	4.41	4.59
Noon	5.57	6.81	4.23	5.7
Afternoon	5.8	4.98	3.95	5.82
Morning	5.56	6.61	4.74	4.96
Noon	5.58	6.43	4.09	5.27
Afternoon	6.29	4.04	4.1	5.47

Fig. 4 Averages of regularity, tempo and 5 second intervals computed by STPA software for four individuals: A - woman, B, C, D – men. Data for all colors (light rows in the table), and separated blue, white and red were visualized in tables

Solving Sudoku - a thinking and reasoning test, required more attention from subjects than STPA-induced clicking task. The main aim of this treatment was to stop thinking about time and focusing strictly on the solved puzzle. Each participant had different tempo of solving the test because of using various algorithms for a solution. After the test volunteers were asked to estimate time of performed task. Subjective time to physical time ratios were calculated for all trials (Fig. 5 B). Only one person could nearly perfectly estimate timing of realized puzzle, while others had a tendency to shorten time of realized task than it was in real.

B. Retrospective Subjective Time Is Disturbed by Increased Physical Activity

In this task, individuals were asked to exercise on the treadmill without control of the time, distance and speed parameters displayed on the machine. Instead, subjects were visually limited to the light source coming from the mask. Subjective walking tempo differed during the day (Fig. 5 C). Observed changes in walking speed were minimal for A, C and D, while in case of B strong increase of subjective walking speed was detected for later hours. Subjective time (ST) to physical time (PT) ratios for jogging and running tests also differed within the time of the day. In all cases, these ratios were lower in later hours meaning that subjective time was shorter than the real time (Fig. 5 B). Also in cases of physical activity, subjective time perception was more interrupted what was visible in higher amplitude of ratio variations. Interesting fact was also observed in a tendency to increase the time duration for treadmill tasks, while Sudoku tasks seemed for people to take shorter time.

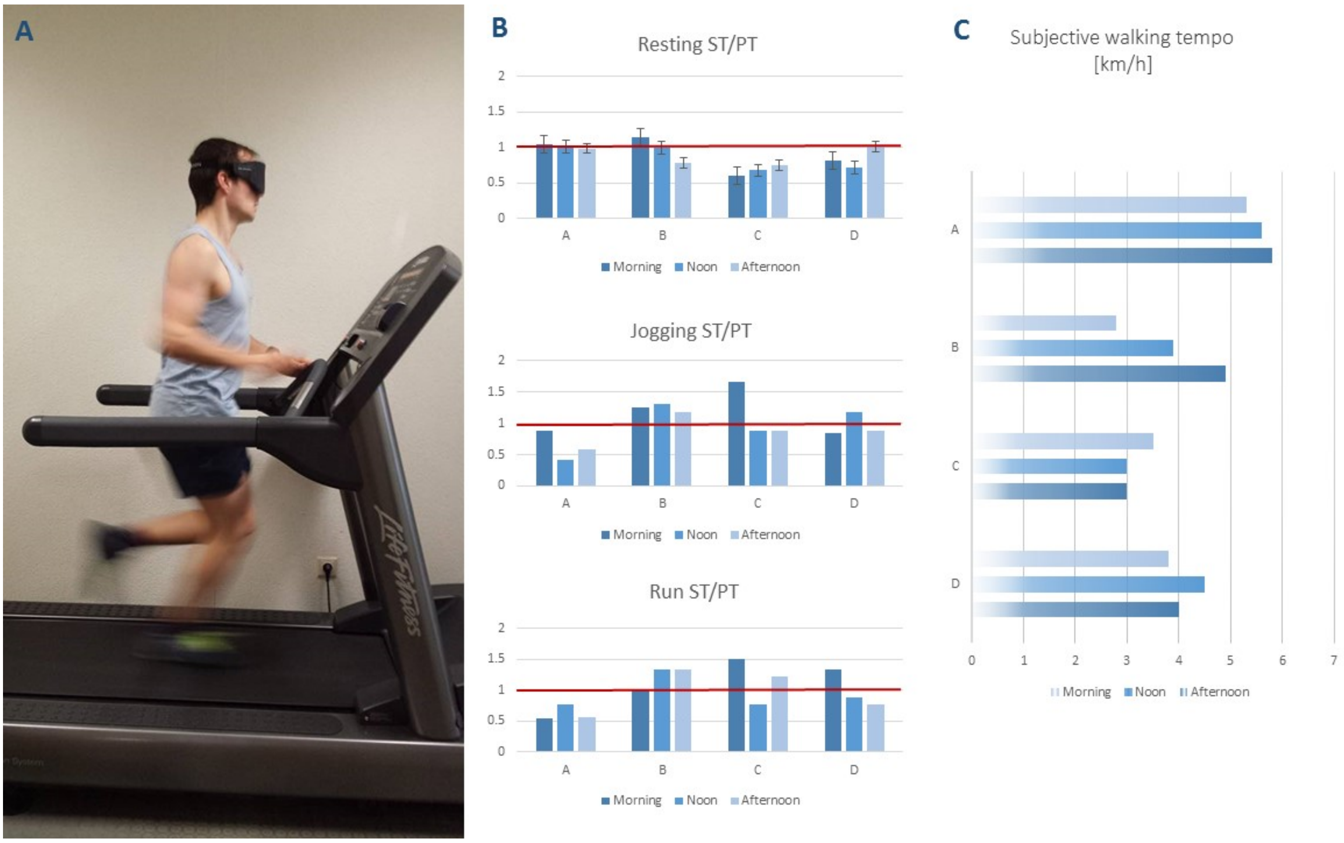
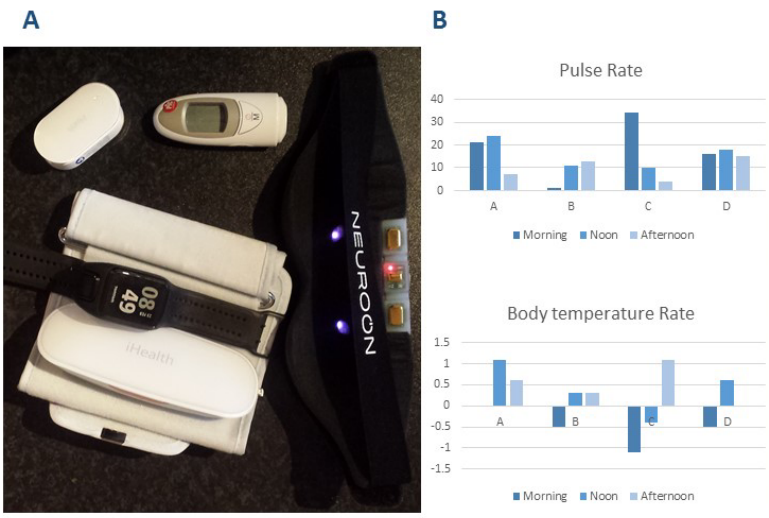


Fig. 5 Results from the treadmill trials. Subjects were performing subjective walking task (C), then jogging task with defined speed of 9 km/h and distance 500 m followed by running at speed of 12 km/h and distance 500 m. Just after realization of a single task, individuals were asked to estimate the timing. Subjective time (ST) to physical time (PT) ratios were shown for resting position after solving Sudoku test, just after jogging task and just after running (B) Red lines indicate case, where subjective time equals the physical one. To attract attention to light, subjects performed this experiment wearing masks equipped with led lighting (A)



C

	Time	Temp	SpO2	PI	Pulse	Sys	Dys	Pulse	Sys	Dys	Pulse
A	10:44	36.7	99	1.7	65	107	77	64	109	78	68
B	09:39	35.4	99	3.1	89	135	80	80	137	76	81
C	09:10	35.4	98	3.9	65	118	60	66	116	59	64
D	10:13	35.3	99	2,0	57	135	85	56	138	87	55
A	11:08	36.7	99	2.6	86	125	91	83	118	88	75
B	09:59	34.9	98	5.3	90	140	82	90	139	78	89
C	09:31	34.3	98	5.4	99	129	83	84	126	83	87
D	10:35	34.8	98	2.5	73	134	96	83	136	87	76
A	12:44	35.6	99	2.1	84	114	84	83	124	80	83
B	13:05	36.6	96	4,1	79	141	79	72	138	76	71
C	13:26	36.9	96	10,6	84	122	59	79	123	58	83
D	13:54	35	98	4,4	65	127	81	61	129	81	63
A	13:03	36.7	99	4,0	108	141	91	96	137	88	92
B	13:17	36.9	97	6,1	90	130	88	87	135	84	88
C	13:41	36.5	96	10,6	94	144	84	103	141	74	95
D	14:17	35.6	97	5,6	83	132	84	77	128	86	74
A	15:48	36.7	99	1.6	77	150	91	73	143	88	69
B	15:29	35	99	1,6	77	150	91	73	143	88	69
C	16:40	35.6	96	6,4	72	122	72	76	116	57	55
D	16:09	35.8	99	5	60	139	80	59	133	80	57
A	16:04	37.3	99	2,9	84	143	93	82	138	93	82
B	15:42	35.3	99	2.3	90	139	85	87	138	82	90
C	16:55	36.7	96	9.8	76	147	78	91	142	84	79
D	16:29	35.8	98	8,1	75	125	79	85	125	81	80

Fig. 6 Medical data were performed by non-invasive electronic devices (A), and visualized in the table (C). Daily changes in pulse rate and body temperature rate are shown in diagrams for each individual. Rates reveal ratio of values measured after the experiment to values collected before the physical activity (B)

C. The Effect of Increased Metabolism on Induced Subjective Time Perception

Time perception may speed up as body temperature rises, and slow down as body temperature lowers [22]. Before and after the treadmill tests, basic physiological data were collected to visualize changes in body temperature, pulse oximetry and blood pressure (Fig. 6). These parameters changed within the time of the day. Particularly, changes in body temperature were observed. Individuals responded differently to sport activity. Again, we did not see similar changes in tested individuals. Observed negative changes in body temperature were caused by sweating.

Just before the treadmill test and just after, subjects were asked to run STPA tests. Small differences in subjective 5 s intervals were observed. Again, no synergic effect between tested individuals was seen (Fig. 7).

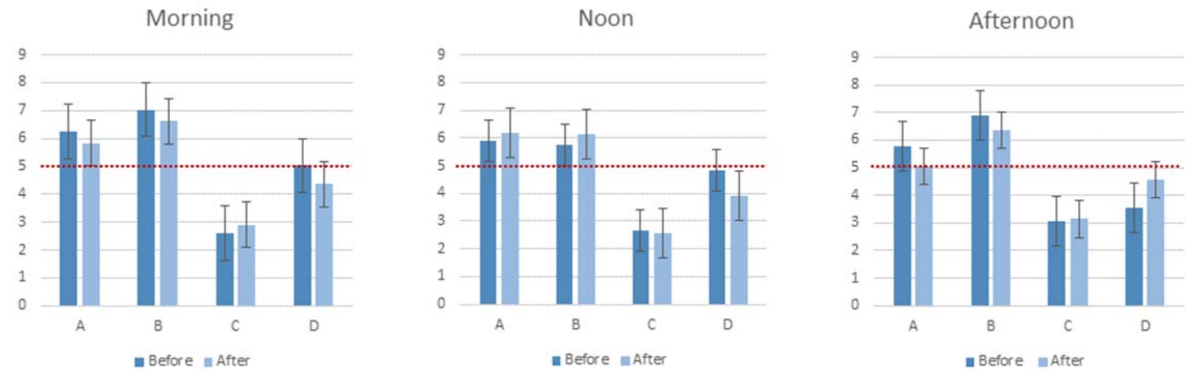


Fig. 7 Subjective 5 s intervals measured by STPA software before and after the treadmill tests in A, B, C, D subjects during morning, noon and afternoon

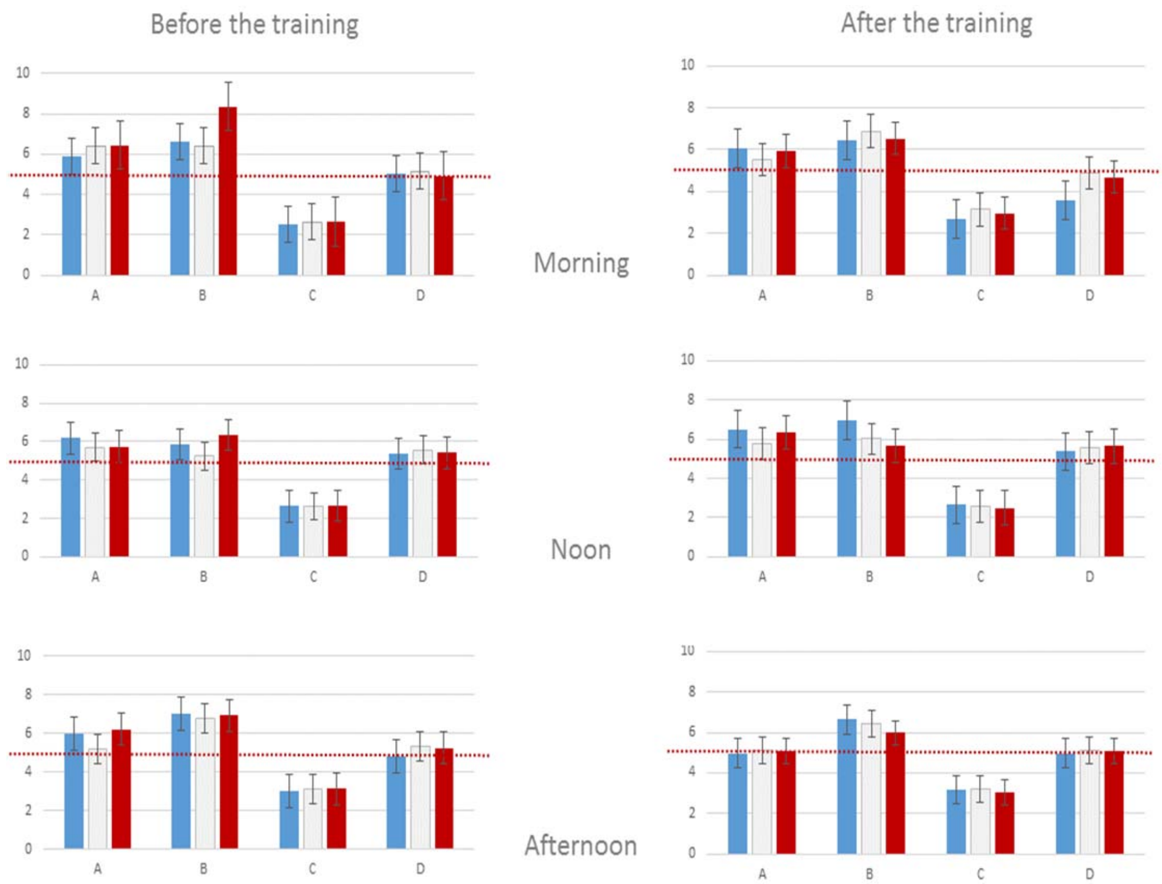


Fig. 8 Diagrams representing average number of clicks per blue, white and red color trials. Red dotted line relates to 5 s interval. Each individual (A, B, C, D), reveals its own time perception pattern characteristic also after metabolism increase

D.The Effect of Colors on Induced Subjective Time Perception

Colors affect behavior and emotions [23]. During STPA test, volunteers were exposed to three types of colors: Exciting long-wavelength red color, relaxing short-wavelength blue color and neutral white (Fig. 8). We did not observe significant changes between colors and time perception in different times of the day; we did not observe emotional changes while performing the clicking task neither. This result suggests that colors may affect time perception through emotional pathway rather than from visual inputs. On the other hand, 1 minute color exposition may not be sufficient to generate changes in behavioral responsivity.

IV. Discussion

In this study we investigated two types of time perception, induced and retrospective, and analysed them in relation to circadian rhythms. Limited number of volunteers allowed us to test described methodology and based on it, draw future roadmap for more precise time perception analysis in this kind of studies.

In general, we observed that induced subjective time perception (expressed in seconds), differs from retrospective estimation of time (expressed in minutes). When thinking in seconds, subjects had a tendency to elongate the time, opposite to recalling temporal events, which caused time underestimation. Induced time perception may be integrated with circadian rhythmicity and cerebellum-regulated neural mechanisms. With focus particularly oriented on time, induced time perception is far more repetitive and accurate than time estimation after attention tests or physical activities. This result supports use of dedicated time perception measuring tools, for example proposed in this work STPA software. Additionally, induced subjective time perception appears to be more stable variable, easy to measure and process in future time-related research.

Subjective time perception at work could be an important factor in interactions between team-mates and even go behind working environment to the private sphere. In specific environment of long-term isolation and confinement (e.g. long-term spaceflights, submarines etc.), subjective time perception can be even more important because prolonged monotony and boredom represent significant stressor, thus also a risk factor [24]-[26]. In these studies, we did not find significant changes in time perception related to circadian rhythms, and related to colors, although more investigations need to be provided in the future.

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