European Journal of Sport Science, 2014
Vol. 14, No. 5, 393–402, http://dx.doi.org/10.1080/17461391.2013.819384

Routledge
Taylor & Francis Group

ORIGINAL ARTICLE

Brainwave entrainment for better sleep and post-sleep state of young elite soccer players – A pilot study

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Abstract
The effect of sleep deprivation on psychophysical performance and well-being is comprehensively investigated. Research investigating the effect of improved sleep is rare. Just as little exists about attempts to support athletic mental state and performance by improving sleep quality. This study aims to investigate whether sleep quality of top athletes can be improved by auditory brainwave entrainment and whether this leads to enhancements of post-sleep psychophysical states. In a pilot study, 15 young elite soccer players were stimulated for eight weeks during sleep with binaural beats around 2–8 Hz. Once a week after wake-up, participants completed three different questionnaires: a sleep diary, an adjective list for psychophysical and motivational state, and a self-assessment questionnaire for sleep and awakening quality. Fifteen sport students executed the same protocol sleeping on the same pillow, but without stimulation. Subjective ratings of sleep and awakening quality, sleepiness and motivational state were significantly improved only in the intervention group, but did not impact their perceived physical state. In summary, eight weeks of auditory stimulation with binaural beats improved perceived sleep quality and the post-sleep state of athletes, whereas the effect on physical level is assumed to occur in a time-delayed fashion. It seems to be worthwhile – to further elaborate long-time effects and consequences on physical and mental performance.

Keywords: *Neurostimulation, auditory stimulation, mental state, athletic performance, sleepiness*

Introduction

Previous research has contributed to knowledge about the importance and multidimensional influence of sleep on human health, performance and well-being (Harvey & Bruce, 2006). Noticeably, most studies deal about the negative effects of sleep deprivation. However, the whole range or potential of sleep is still not entirely investigated. In particular, in the field of high-performance sports, where health, well-being and an optimal psychophysical state is obligatory for maximal performance, the benefit of sleep is not utterly examined and ways to improve sleep are not exhaustively tested.

Research that attempts to improve sleep duration or sleep quality is surprisingly rare, although the impact and potential of sleep on both health and performance are known. For instance, when a sleep extension of about an hour (from 7.5 to 8.5 hours) was added by Kamdar, Kaplan, Kezirian, and Dement (2004), it revealed improved vigilance and mood. Recently, Mah, Mah, Kezirian, and Dement (2011) investigated the effect of sleep extension on athletes' performances. In this study, university basketball players included five to seven weeks of sleep extension (6–9 hours + 2 hours), and they found that the extended sleeping time leads to faster performance in sprints, improved shooting accuracy, decreased mean reaction time and sleepiness scores, plus higher vigour and lower fatigue ratings. In addition, athletes stated to have an overall better physical and mental well-being during practices and games.

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For top athletes with tight work and training schedules, it is hardly feasible to simply extend sleeping time. But the question arises, whether a comparable effect could be evoked if the hours of sleep they have are improved in the quality of their sleep.

The physical process of sleep can be determined by objective parameters; however, the subjective perception plays a very important role for the rating of sleep quality (Heitmann et al., 2011). Sleep quality is also determined by the amount and amplitude of specific brainwaves during sleep, namely alpha-, theta- and delta waves between 1 and 9 Hz (Guilleminault & Kreutzer, 2003; Iber, Ancoli-Israel, Chesson, & Quan, 2007; Rodenbeck et al., 2006). These frequencies are known to be repeated in a specific order reflecting the different sleep stages. The sleep stages included: going to sleep, awake, relaxed state with eyes closed – alpha frequencies 8–13 Hz dominate; sleep stage 1 – predominantly theta frequencies 4–7 Hz; stage 2 – persistent theta frequencies plus sleep spindles 11–16 Hz; stage 3 – delta frequencies 0.5–2 Hz (transmission into deep sleep); stage 4 – more than 50% delta frequencies; sequence of sleep stages lasts about 90 minutes (=sleep cycle), which is repeated about five to seven times per night (Iber et al., 2007).

Stimulating the brain during sleep with such frequencies between 1 and 9 Hz in a sequence mimicking the healthy human sleep cycle is called brainwave entrainment. It provides an option to influence the sleep quality of athletes non-invasively and without any time-consuming, stressful or even invasive interventions (Rhodes, 1993; Wilson, 1990). Using auditory stimuli of different frequencies for brainwave entrainment, literature provides evidence of the neurophysiological effect showing that the brain picks up the frequencies it is stimulated with (Karino et al., 2004; Pratt et al., 2009; Schwarz & Taylor, 2005). Although the exact underlying mechanism is not well understood (Pratt et al., 2009), there is also proof for the effect of brainwave entrainment on psychomotor performance and mood (Lane, Kasian, Owens, & Marsh, 1998; Wahbeh, Calabrese, & Zwickey, 2007). Moreover, evidence exists that auditory stimulation can be used as an aid for falling asleep (Rhodes, 1993; Wilson, 1990).

The aim of this pilot study was to test whether brainwave entrainment allows improving sleep quality and post-sleep state of high-level soccer players. It is hypothesised that brainwave entrainment is able to improve quality of sleep, amongst others via decreasing time before falling sleep (Rhodes, 1993; Wilson, 1990).

Improved sleep quality is assumed to have comparable effects to sleep extension or opposite effects than sleep deprivation. Accordingly, enhanced psychophysical states of athletes are expected (Azboy & Kaygisiz, 2009; Dotto, 1996; Durmer & Dinges, 2005; Ichikawa et al., 2008; Lim & Dinges, 2008; Minkel et al., 2012; Rakitin, Tucker, Basner, & Stern, 2012; Skein, Duffield, Edge, Short, & Mundel, 2011; VanHelder & Radomski, 1989; Waterhouse, Atkinson, Edwards, & Reilly, 2007).

Whether the effect of brainwave entrainment is noticeable after days or weeks is not easy to speculate, as literature so far is mainly restricted to short-term neurophysiological effects of brainwave entrainment or to sleep deprivation. Similar to the sleep extension study by Mah et al. (2011), we would predict that some effects (especially physical effects) develop/enhance over time.

Methods

For this pilot study,18 young sub-elite male soccer players (aged 16.28 ± 1.02 years; mean height 179.78 ± 6.18 cm; mean weight 70.78 ± 7.82 kg) out of the under 17 (U17, $n = 11$) and under 19 (U19, $n = 7$) selection of a German Soccer League team took part voluntarily in this intervention study (intervention group (IG)). Both teams played in the German Soccer League West, the highest league of their age group. As a control group (CG), 21 sport students (10 females, 11 males, aged 22 ± 3.12 years; mean height 176.19 ± 8.49 cm; mean weight 68.81 ± 11.10 kg) have been recruited from the university.

The university ethic committee approved the study. All participants stated prior to the study to be healthy and to have no manifest sleep problems, which were the inclusion criteria for our study. No dietary restrictions were given. Participants (and parents in case of being under age) were informed about the aim and purpose of the study (IG: testing the stimulation device; CG: testing the pillow), and asked to sign a consent form. They were instructed about when and how to fill out the intended questionnaires. Questionnaires were answered on a fixed day once a week shortly after wake-up (approximately 30–60 minutes) within an individually fixed timeslot. The timeslot was given in order to standardise time and conditions for answering of questionnaires.

The first baseline was collected over two weeks. Afterwards, the pillows were handed out to the participants for the following eight weeks of the intervention phase. The IG was tested during the competition season, which consisted out of high physical and psychological loads and competitions at regular intervals. The CG was tested during the semester term containing high physical and mental

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workloads and examinations (Block 2 of the CG took place during a holiday break).

Intervention

During the intervention period, participants of both groups slept for eight weeks on an ergonomic pillow with integrated high-quality speakers on the left and right top corner. Only for the IG, the pillow was connected to an auditory device (inPulser) with a high sound quality of 24-bit/96 kHz manufactured by INFRASONCIS GmbH, Cologne, Germany (for further information please visit: www.inpulser.de).

For entrainments of sleep brainwaves, two coherent sounds (Born & Wolf, 1999) of nearly the same frequencies are applied via two different channels each to one ear. The frequency-following response in the brain results out of the difference of the two sounds (Oster, 1973; Pratt et al., 2009). Accordingly, presenting one sound of 400 Hz to one ear and of 404 Hz to the other, the frequency-following response in the brain is 4 Hz. Only by taking the advantage of the "physical trick" – presenting the same music via two loudspeakers slightly shifted in time – allows creating such low frequencies. Thus, the music acts as a carrier for the frequencies. The third emerging frequency is called the binaural beat. Monaural beats (two tones of different frequencies combined before applying them via one channel) were integrated in order to enlarge the binaural beat stimulus and to suppress counterproductive frequencies (for further information about binaural and monaural beats please see Oster, 1973; Pratt et al., 2009; Schwarz & Taylor, 2005; VanHelder & Radomski, 1989).

The stimulus material for this study consisted of four frequency periods starting with 22.5 minutes of alpha frequencies around 8 Hz, followed by 22.5 minutes of theta frequencies around 6 Hz, 22.5 minutes of delta frequencies around 2 Hz and finally 22.5 minutes of theta frequencies around 4 Hz. These four 22.5-minute periods and specific order of frequencies represent one healthy 90-minute sleep cycle (Guilleminault & Kreutzer, 2003) and are repeated as long as the device is turned on. Participants have been instructed to turn the device on when going to bed and the volume of the music as low as convenient without being disturbed by the music. By reducing the volume, it was not possible to turn off the device, and it is known that the binaural beat is perceived even if the signal is below the threshold of hearing (Oster, 1973).

Questionnaires

Three questionnaires were applied in this study in order to monitor the sleep behaviour. It included a sleep diary, sleep and awakening quality (Self-Assessment questionnaire of Sleep and Awakening quality (SSA)), as well as psychophysical state of participants (Mood).

Sleep diary. First, participants were asked to fill out a sleep diary including the following questions: at what time did I go to bed?; How long did it take until I fell asleep?; I think I woke up . . . times during the night. I think, I have been awake . . . hours and . . . minutes. I think I woke up at . . . in the morning. I think I did sleep . . . hours and . . . minutes in total this night. I did get up at . . . I would rate my sleep quality this night on a scale from 1 (very bad) up to 10 (very very good). The sleep diary was sent via email to each participant and was returned by participants the same way after completion within the intended timeslot.

SSA. For sleep ratings, the SSA developed and validated by Saletu, Wessely, Grünberger, and Schultes (1987) was used. The SSA includes 20 questions concerning sleep and awakening quality as well as somatic complaints. The subject has to choose the answer between "no" (=1), "a little" (=2), "moderately" (=3) or "a lot" (=4), depending on the last night and current feelings after wake-up. Four scores are calculated out of the 20 items as the sum of the ratings. Transmission of the SSA from operator to participant and back was the same as for the sleep diary.

Mood. Participants have been provided in the intended timeslot with a link to a web-based adjective list. The list consisted out of the body finder (dimension *perceived physical state*; 20 adjectives divided into physical energy, fitness, flexibility and health), which has been validated on a total of 645 people (Cronbach's alpha intraclass correlation coefficient .82 and .92) for the assessment of short-term changes of mood in athletes (Kleinert, 2006), and the feel finder (dimensions *psychological strain* were divided into sleepiness, mood, calmness and recovery) and *motivational state* (divided into self-confidence, willingness to seek contact, social acceptance and readiness to strain); there were 16 adjectives in total, which include a short form of the "Eigenzustandsskala" (Nitsch, 1974). Ratings were executed on a scale from 0 (not at all) to 5 (absolutely). The online questionnaire was completed after the sleep diary and SSA.

Statistics

Three out of the IG (U19 team) and 6 (2 males, 4 females) out of the CG dropped out in the course of the study due to private reasons or handed back

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incomplete data-sets. The answers for each variable of the remaining 15 participants of the IG and CG were averaged over 2 weeks each into 5 blocks. They included pre (week 1 + 2 baseline without pillow + music); block 1 (week 3 + 4 intervention with pillow + music or pillow); block 2 (week 5 + 6 intervention with pillow + music or pillow); block 3 (week 7 + 8 intervention with pillow + music or pillow); and block 4 (week 9 + 10 intervention with pillow + music or pillow). Averaging into blocks was undertaken to balance daily state variability.

Statistics were run with STATISTICA 7.1 (Stat Soft Inc., Tulsa, USA). The statistic of interest was for all variables the difference between blocks, groups as well as the interaction. All non-parametric variables have been analysed using the Wilcoxon test for paired samples. In case of significance, Friedman's analysis of variance (ANOVA) was used for post hoc tests. Blocks of the parametric variables were compared using the repeated-measures ANOVA. For significant results from the ANOVA, the Fisher's least significant difference post hoc test has been used. Effects of gender (6 females, 9 males) within the CG have been calculated using the Mann–Whitney U-test for the non-parametric variables and by ANOVA including the factor code "gender". For all non-parametric values and scores applies: the higher the score the better. Statistical significance was reached at $p < 0.05$ (*), $p < 0.01$ (**) and $p < 0.001$ (***).

Results

Sleep diary

ANOVA comparing parameters of the sleep diary prior to with the blocks during the intervention revealed no significant changes for the IG (see Table I). For the CG, significant higher values for block 2 were found for time going to bed and time standing up. Significant lower values of times awake were revealed comparing pre with blocks 2, 3 and 4.

Significant differences between groups have been found for time going to bed and total sleep time and an interaction as been found for time going to bed and time standing up due to the high scores of the CG at block 2. No interactions have been revealed for the remaining items (minutes until falling asleep: $p = 0.17$; times ($p = 0.90$) and minutes awake ($p = 0.37$); total sleep duration ($p = 0.91$)).

Using Friedman's ANOVA, significant changes have been found for the subjective rating of sleep quality of the IG. Ratings of subjective rating of sleep quality on a scale from 1 to 10 prior to the intervention were significantly lower compared to all blocks during the intervention (see Table I). A gender effect has been identified within the CG showing that females were going earlier to bed then men ($p = 0.02$) and rating their subjective sleep quality higher than men ($p = 0.05$).

SSA

The four scores of the SSA questionnaire obtained significant increases for the IG during the intervention compared to baseline (see Figure 1). Wilcoxon test for paired variables revealed that for SSA-1 (sleep quality) the score of block 4 is significantly higher compared to pre ($p = 0.04$) and lower compared to block 3 ($p = 0.03$). For SSA-2 (awakening quality) and SSA-4 (total score), scores of pre were found to be significantly lower compared to blocks 1, 2, 3 and 4 (for all blocks of SSA-2, $p < 0.001$, for all blocks of SSA-4, $p < 0.001$). For SSA-3 (somatic complaints), pre was found to be lower than block 1 ($p = 0.05$) and 2 ($p = 0.01$), and block 2 was higher than block 4 ($p = 0.01$). The CG showed no significant changes. Significant differences were found between groups for all SSA scores showing lower ratings of the CG in all cases (all $p < 0.001$). Within the CG, females rated their somatic lower than men ($p < 0.05$).

Mood

For the IG, the body and feel finder measuring perceived physical state, psychological strain and motivational state revealed a significant change in motivational state only (see Table II and Figure 2). As a result of the Wilcoxon test block pre was found to be lower than block 1, block 2 and block 4. The sub-dimension "sleepiness" of the dimension psychological strain showed a decreasing score in the course of the intervention period with significantly lower values in block 4 compared to block pre, block 1 and block 3. For perceived physical state as well as its sub-dimensions, no significant difference between the blocks could be shown.

For the CG, significantly lower physical state was found for block 4 compared to pre. Physical energy was lower for blocks 3 and 4, compared to pre and block 1 ($p < 0.05$). Physical health was reduced from block 1 to 4 ($p = 0.04$). Regarding mood, significantly higher ratings were found for block 2 compared to pre ($p = 0.01$).

Comparisons between groups have shown lower ratings of the CG for the dimension perceived motivational state and its sub-dimensions besides self-confidence. Lower ratings of physical fitness and recovery of the CG compared to the IG have been found, whereas the CG rated their sleepiness higher than the IG. No gender effects have been found within the CG (physical state: $p = 0.81$; psychological state: $p = 0.72$; motivational state: $p = 0.44$).

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Table I. Results of sleep diary comparing measurement blocks pre, 1, 2, 3 and 4 for metric variables of the IG and CG

		Pre		Block 1		Block 2		Block 3		Block 4		Results within		Results between	
Sleep diary	Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*F*	*p*	*F*	*p*
Time going to bed (8pm + minutes)	IG	209.23	71.31	216.53	101.73	196.77	64.96	175.63	69.74	189.33	70.41	2.42	0.06	5.66	0.03
	CG	200.67	75.26	237.21	61.54	365.35	114.02	234.67	65.72	207.33	60.92	17.29	<0.001		
Time standing up (5am + minutes)	IG	209.73	66.83	183.77	93.96	154.77	69.72	166.22	73.88	170.70	49.54	2.26	0.07	<0.01	0.96
	CG	128.80	65.14	140.38	35.70	286.96	68.13	170.67	65.38	153.68	51.18	32.86	<0.001		
Min until falling asleep	IG	20.60	21.16	12.77	14.51	13.20	17.53	11.63	15.94	9.27	6.94	2.03	0.10	0.33	0.57
	CG	20.00	16.48	13.94	9.20	10.12	6.28	15.73	8.64	20.19	24.17	1.70	0.16		
n times awake	IG	1.10	1.26	0.57	0.70	0.47	0.69	0.60	0.89	0.67	0.70	1.72	0.16	3.23	0.09
	CG	1.40	0.91	1.07	0.98	0.72	0.72	0.80	0.84	0.96	0.58	3.03	0.02		
Min awake	IG	9.03	12.43	3.20	4.20	3.30	5.49	10.73	22.54	5.97	10.01	1.21	0.32	0.04	0.85
	CG	8.57	8.35	6.15	6.40	3.88	4.12	6.57	8.30	10.95	12.78	1.67	0.17		
Total sleep time	IG	509.37	59.74	496.00	78.38	489.60	68.25	497.27	57.35	508.40	52.14	0.55	0.70	20.80	<0.01
	CG	436.33	71.05	415.59	58.14	429.08	82.46	430.43	76.40	448.52	57.41	0.62	0.65		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	χ^2	*p*	χ^2	*p*
Subjective sleep quality	IG	6.33	1.19	7.58	1.00	7.65	1.40	7.94	1.54	7.95	1.29	5.97	<0.001	23.57	0.01
(1–10)	CG	6.69	1.53	6.67	1.64	6.76	1.36	7.07	1.71	7.06	1.55	5.02	0.28		

Note: Indicated are mean, SD, *F*- and *p*-values (for subjective sleep quality χ^2, and *p*-value) for the comparison between blocks within groups and between groups, respectively.

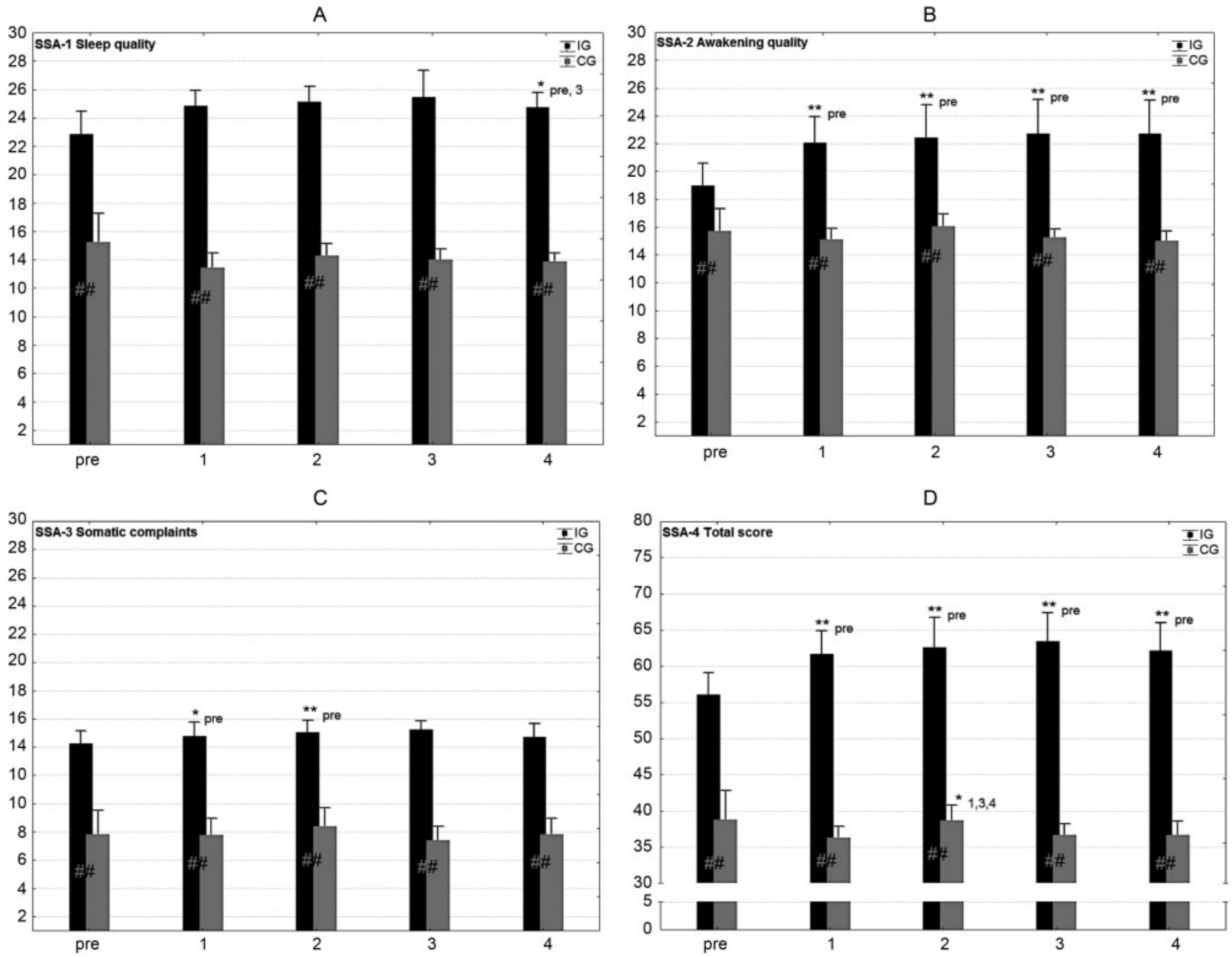

Figure 1. Progression of subjective sleep and awakening quality rated on a scale from 1 to 4 for measurement blocks pre, 1, 2, 3, 4 of the IG (black) and CG (grey) presented with confidence intervals (95%) for the four different scores regarding sleep quality (A), awakening quality (B), somatic complaints (C) and total score (D).
Notes: Significant differences within groups are indicated by * ($p < 0.05$), ** ($p < 0.01$) plus the name of the regarding measurement. Differences between groups are indicated by ## ($p < 0.001$).

Discussion

This pilot study aimed to improve sleep quality and perceived post-sleep psychophysical state of young elite soccer players via auditory brainwave entrainment. The results of three different questionnaires showed that auditory stimulation had a positive effect on sleep and awakening quality and sleepiness, confirming the hypothesis. These results are in accordance with previous investigations about sleep extension (Ichikawa et al., 2008; Kamdar et al., 2004; Mah et al., 2011; Waterhouse et al., 2007).

Perceived physical state was not improved within this study, contrary to the hypothesis and what has been shown before by performance tests (Mah et al., 2011; VanHelder & Radomski, 1989; Waterhouse et al., 2007) under consideration that no objective performance tests were applied within this study.

The sleep behaviour of the participants did not significantly change during the study, with the exception of sleeping behaviour of the CG at block 2 (time going to bed, standing up and being awake at night), which temporally changed due to holiday. IG generally went to bed earlier than the CG, which also resulted in higher total sleep time. Towards the end of the experimental phase the IG tends to fall asleep quicker compared to the CG, suggesting a positive effect of the stimulation as shown before (Rhodes, 1993; Wilson, 1990). IG rated their sleep and awakening quality during the eight weeks with auditory stimulation higher compared to baseline and compared to the CG, whereas the CG only showed a slightly higher total score (SSA-4) for block 2 during their holidays.

This is also in congruence with the results for "sleepiness" of the mood questionnaire indicating

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Table II. Results mood questionnaire (mean, SD and χ^2, p-values) comparing blocks pre, 1, 2, 3 and 4 of the three dimensions and their four sub-dimensions, respectively, of the IG and CG for the comparison between blocks within groups and between groups, respectively

		Pre		Block 1		Block 2		Block 3		Block 4		Results within		Results between	
Mood	Group	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	χ^2	p	χ^2	p
Perceived physiological state	IG	2.39	0.36	2.46	0.59	2.40	0.43	2.51	0.58	2.23	0.36	3.81	0.43	15.28	0.08
	CG	2.37	0.28	2.34	0.26	2.27	0.18	2.23	0.19	2.18	0.23	9.73	0.05		
Physical energy	IG	2.16	0.81	2.11	1.21	1.79	1.36	2.24	1.12	1.32	1.28	8.04	0.09	16.24	0.06
	CG	2.35	0.96	2.39	0.91	1.96	0.77	1.89	0.94	1.78	0.74	11.44	0.02		
Physical fitness	IG	2.95	0.83	3.25	0.70	3.57	0.76	3.30	0.95	3.61	0.94	7.84	0.10	29.14	<0.001
	CG	2.61	0.64	2.53	0.81	2.84	0.70	2.71	0.86	2.88	0.64	8.26	0.08		
Physical flexibility	IG	2.45	0.53	2.34	0.74	2.35	0.59	2.42	0.77	2.15	0.49	4.03	0.40	5–24	0.81
	CG	2.67	0.53	2.43	0.45	2.60	0.60	2.35	0.30	2.35	0.48	3.67	0.45		
Physical health	IG	2.00	0.54	2.14	0.68	1.90	0.69	2.08	0.67	1.87	0.68	3.08	0.54	12.16	0.20
	CG	2.67	0.62	2.02	0.44	1.94	0.56	1.98	0.46	1.86	0.60	13.49	0.01		
Perceived psychological strain	IG	2.94	0.34	3.20	0.47	3.05	0.36	3.07	0.55	2.93	0.65	4.64	0.32	7.52	0.58
	CG	2.78	0.74	2.92	0.50	3.09	0.56	3.13	0.53	2.97	0.54	7.52	0.58		
Calmness	IG	3.33	0.65	3.65	0.67	3.47	0.65	3.57	0.82	3.57	0.95	3.30	0.51	7.31	0.60
	CG	3.17	1.14	3.36	0.82	3.34	1.06	3.67	0.98	3.37	0.87	6.58	0.16		
Mood	IG	3.20	0.71	3.67	0.62	3.51	0.77	3.50	0.93	3.59	1.10	2.75	0.60	13.28	0.15
	CG	2.80	1.37	2.97	0.90	3.34	1.05	3.17	0.96	3.07	0.95	10.91	0.03		
Recovery	IG	2.77	0.67	3.42	0.95	3.45	0.90	3.18	1.01	3.25	1.30	7.51	0.11	18.23	0.03
	CG	2.57	1.22	2.55	0.78	2.98	0.79	3.07	0.92	3.02	1.01	5.99	0.20		
Sleepiness	IG	2.46	0.66	2.06	0.59	1.77	0.95	2.03	0.75	1.30	1.12	11.99	0.02	32.70	<0.001
	CG	2.60	1.07	2.79	0.82	2.70	0.78	2.60	1.08	2.39	0.88	3.59	0.46		
Perceived motivational state	IG	3.08	0.58	3.42	0.60	3.40	0.72	3.56	0.75	3.62	0.86	12.82	0.01	33.43	<0.001
	CG	2.70	0.79	2.70	0.97	2.89	0.76	2.84	0.96	2.94	0.79	4.39	0.36		
Social acceptance	IG	3.45	0.66	3.81	0.67	3.72	0.97	3.96	0.94	3.95	0.92	8.96	0.62	28.66	<0.001
	CG	2.87	1.17	2.73	1.20	2.94	1.15	2.95	1.08	2.98	0.90	2.53	0.64		
Willingness to seek contact	IG	2.71	0.54	3.17	0.68	3.07	1.04	3.31	0.87	3.36	0.89	9.08	0.60	21.36	0.01
	CG	2.47	1.08	2.41	1.15	2.54	1.02	2.38	1.18	2.73	0.96	2.20	0.70		
Self-confidence	IG	3.16	0.60	3.47	0.63	3.55	0.72	3.60	0.78	3.69	0.84	8.49	0.08	11.73	0.23
	CG	3.00	0.98	3.14	1.09	3.15	0.74	3.22	1.09	3.18	0.82	1.83	0.77		
Readiness to strain	IG	3.00	1.16	3.23	0.88	3.24	0.87	3.35	1.10	3.48	1.21	3.75	0.44	20.26	0.02
	CG	2.47	1.13	2.52	0.90	2.92	0.87	2.80	1.0	2.86	0.90	4.61	0.33		

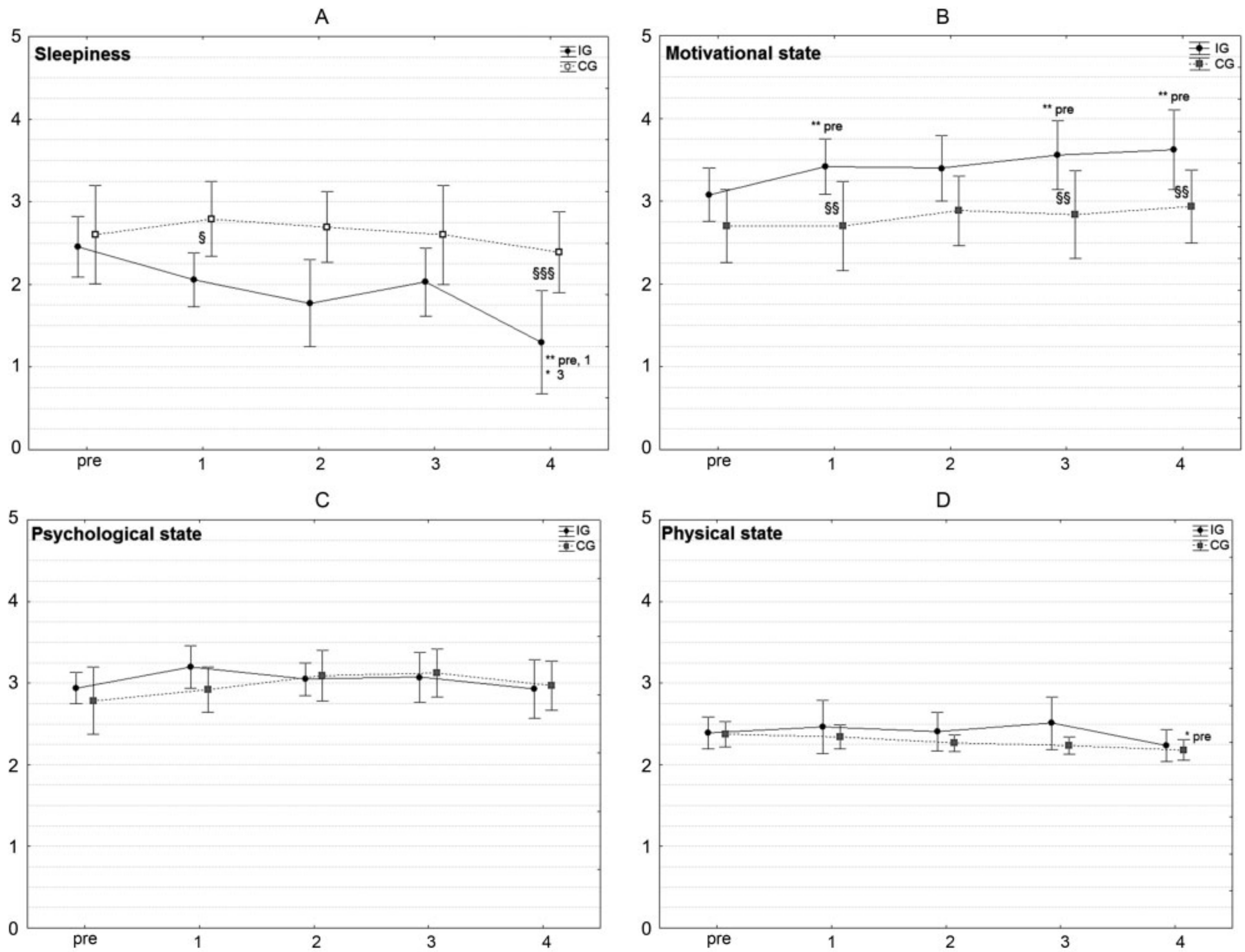

Figure 2. Progression of the sub-dimension sleepiness (A) and dimensions motivational (B), psychological (C) and physical state (D) of the mood questionnaire rated on a scale from 0 to 5 for measurement blocks pre, 1, 2, 3 and 4 presented of the IG (black) and CG (grey) with confidence intervals.
Notes: Significant differences within groups are indicated by * ($p < 0.05$), ** ($p < 0.01$) plus block name/number. Differences between groups are indicated by § ($p < 0.05$), §§ ($p < 0.01$), §§§ ($p < 0.001$).

lower and decreasing sleepiness of the IG compared to the CG. The CG did show consistent lower scores compared to the IG regarding the sleep and awakening quality scores. Therefore, the group effect per se does not support the benefit of brainwave entrainment. However, the effect of stimulation is supported by the fact that the CG did only show a slight improvement at block 3 for the total SSA score but no other changes over time, whereas the IG did show improvements during the course of intervention.

Similarly, a significant improvement within the dimension "motivational state" was found only within the IG, while the motivational state of the CG was consistently lower, but did not show any changes over time. The related sub-dimensions of the IG failed to reach significant changes over time. The improved sleep quality is therefore assumed to contribute to an overall improved perceived readiness to act. This is in line with the improvements within awakening quality scale (SSA-2), including its sub-dimension "ready for daily activities" and "readiness to strain".

Based on what has been shown before in sleep deprivation or extension studies (Azboy & Kaygisiz, 2009; Ichikawa et al., 2008; Kamdar et al., 2004; Lim & Dinges, 2008; Mah et al., 2011; Minkel et al., 2012; Skein et al., 2011; VanHelder & Radomski, 1989; Waterhouse et al., 2007), no consistent effect within the dimensions perceived psychological strain and physical state was found unexpectedly. But the effect of auditory brainwave entrainment on psychological and physical state cannot generally be neglected as the difference between groups regarding "physical fitness" and "recovery" becomes mainly evident during the intervention period. Thus, IG seems to profit from the stimulation. Sub-dimensions of psychological strain like "calmness" or "mood", which were supposed to react in congruence to sleep quality and sleepiness, seem to be subject to a ceiling effect. Mood was temporarily

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improved within the CG for block 2, which – again – is suggested to be caused by holiday. Decreased ratings of physical state and energy of the CG at block 4 seemed to be caused by simultaneously decreased physical health.

The inexplicit effect of brainwave entrainment on perceived physical state might be due to the fact that consequence of improved sleep quality on perceived physical state is a long-term or time-delayed effect, and the duration of the intervention period was too short to obtain such positive developments. Effects on physical state are known to react slower, e.g. for stress. Stress is known to cause serious effects on the cardio-vascular and immune system and feelings of lack of energy and depression not after one stressful day or week, but in the long run (Born & Wolf, 1999). Remarkably, Mah et al. (2011) revealed, besides improved sleepiness and vigour, improved physical performance after five to seven weeks of sleep extension. It can only be speculated whether this divergence is due to the difference between sleep extension and improved sleep quality.

At this point it should be mentioned that it was planned also to recruit the CG out of the soccer teams and to integrate some physical performance tests. However, it was hard convincing top athletes to test new things and to risk that this might impair their performance and the coaches were afraid of producing supplementary stress on the young athletes. This is a common problem for studies testing top athletes during the competition season.

The CG of young sport students was suggested to adequately meet the characteristics of the elite athletes, but, as mentioned earlier, some differences in the "pre" measurements (see SSA) are evident. For future investigations it is recommended to compare two groups of the same pool (e.g. one team). The holiday during block 2 of the CG was suspected to interfere, but was shown to be only of marginal and temporary extent (block 2 for total score and sleep diary).

The gender effects are only of relevance concerning the somatic complaints score, where lower ratings of "somatic complaints" of females compared to men of the CG might have contributed to the group differences comparing the IG and CG. In all other cases for which a gender effect has been identified, the results comparing groups would have been even clearer without females, as females rated their subjective sleep quality within the sleep diary higher and went to bed earlier than men. Concerning seasonal timing of data collection, no general improvements or decrements were notified. To exclude possible effects, seasonal timing should be addressed in future studies.

Consequently, during eight weeks of brainwave entrainment, higher subjective ratings of sleep and awakening quality, sleepiness and motivational state were obtained. First evidence for the positive effect of brainwave entrainment on sleep quality and post-sleep stage within young sub-elite soccer players is given. It remains to be shown whether it becomes manifested in physical performance and if it can be repeated within professional athletes. Reports of several elite athletes are promising. Continuing investigations should include objective measurements, like actigraphy or polysomnography, during sleep and performance tests to track and prove the effect of brainwave entrainment on sleep quality and quantity, as well as physical performance.

Conclusion

In conclusion, brainwave entrainment during sleep seems to be a valuable method to support and improve sleep quality and post-sleep mental state of athletes in a non-invasive, timesaving and comfortable way. Improved sleep quality and mental state might support training and competition efforts of athletes, and in the long run might lead to improved psychophysical performance. First evidence and approach for future elaborations are provided within this pilot study. Further areas of application also in the general population, such as in therapy, school or business, are suspected.

Acknowledgement

Our thanks go to the volunteering soccer players and their teams for their trust, engagement and valuable time they invested in this study. Special thanks goes to Jasmin Martinetz for her help with data collection and analysis. Furthermore, we would like to express our gratitude to Uwe Storch from Infrasonics GmbH for the technical and personal support and to the unknown reviewer for his/her valuable comments.

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