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Commentary

The Awakening Futures Sound Positive! Commentary on the Efficacy for Audio to Counteract Sleep Inertia

Stuart J. McFarlane*, Jair E. Garcia and Adrian G. Dyer

School of Media and Communication, RMIT University, Melbourne, Vic, 3001, Australia

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INTRODUCTION

The feeling of grogginess and lack of alertness one may experience upon, and post-awakening is a physiological phenomenon termed 'sleep inertia' [1-3]. Compared to wholly awake participants, individuals experiencing sleep inertia show decrements in performance which can be reflected in significantly poorer accuracy, memory, complex decision making, and slower reaction time (RT). The duration and severity of sleep inertia is variable and can be influenced by factors such as sleep stage at awakening, sleep deprivation, time of day, as well as a variety of reactive countermeasures [4] like caffeine [5-7] or lighting treatments [8-10]. Research suggests that a typical bout of sleep inertia may last for approximately 30 minutes, however, durations of up to 4 hours have also been reported [1,11-15]. Indeed, in many scenarios sleep inertia represents a multidimensional performance decrement that has the proven potential to negatively impact real-world situations and is frequently highlighted as a research field requiring improved understanding to allay such occurrences [16-23]. For example, in the 2010 Air India Express air crash disaster that resulted in 158 fatalities, it has been shown that the captain of the aircraft had recently woken from an in-flight nap prior to the accident. The poor decisions made by the pilot in the time-frame from awakening to crashing were attributed to the disaster and have been linked to the effects of sleep inertia [23]. Tragedies such as this highlight the importance of maintaining situational awareness in demanding and critical settings. In everyday scenarios, the impacts of sleep inertia cannot be underestimated. It is estimated that on a global economic scale the financial losses as a result of sleep deprivation (a known factor to enhance sleep inertia) amount to hundreds of billions of dollars annually [24,25]. Thus, countermeasure treatments for the reduction of sleep inertia are warranted to ensure safety among citizens in public space, domestic, and employment settings.

One emerging practical and efficient field which explores techniques to neutralize the effects of sleep inertia is the study of auditory countermeasures [26]. Auditory research seeks to understand if treatments sounded pre, and post-awakening may counteract sleep inertia, and is grounded in psychophysics research on auditory perception and cognition. It has been well appreciated for some time that sounds can have significant effects on the state of mind in the human brain [27,28]. For example, in awake and alert humans, several sound types including white noise, environmental sounds, and music have been shown to enhance arousal and improve task performance [29-33]. Furthermore, in the awakening of humans, Auditory Arousal Thresholds (AAT's) have been researched to understand the time it may take an individual to awaken in response to different alarm sounds [34]. A recently published systematic review by McFarlane et al. (2020) reports on the current state of knowledge of auditory countermeasures for sleep inertia [26]. A systematic review captures and reports on all relevant published work in peer-reviewed journals in a very formal way; and below we discuss for professionals and the general public the implications for work-related practices and future research based on current findings.

Auditory Countermeasures in Context

The current state of research on auditory countermeasures for sleep inertia may be structured into two categories including (i) emergency, and (ii) non-emergency awakenings. Emergency awakenings describe research designs that are intended to abruptly wake participants from slow-wave sleep, often at inconvenient times, or by surprise during nocturnal sleep. This field of research is of high value due to the urgent need in some scenarios for people to quickly awaken and make critical decisions like avoiding fire, or responding to industrial or military incidents [34-36]. Emergency focused studies attempt to replicate life-threatening real-world scenarios and have been conducted in both laboratory and field settings. Non-emergency awakenings (or casual awakenings) allow

***Correspondence to**: Stuart J. McFarlane, School of Media and Communication, RMIT University, Melbourne, Vic, 3001, Australia, Tel: 0419880695; E-mail:mail@stuartmcfarlane.com

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the participant to naturally awaken to the stimulus without the pseudo-emergency intervention to analyse sleep inertia in everyday settings. Within these two research categories, a number of context-dependent auditory treatments are employed; however, the overlap of stimulus treatments between emergency and casual awakening studies have yet to be explored. For example, emergency awakening research has analysed audio-frequency variations, voice warnings, and signal sequences, and is primarily driven by AAT investigations centred on emergency fire alarm effectiveness [37-44]. Non-emergency studies have recently tested musical treatments by employing remote testing with smartphone-enabled technologies that enable ecologically valid sleeping routines in a participant's own house. Such research was not feasible prior to innovations in smart phone app deployments and now reveals that participant's preference for melodic music significantly correlates with reported reductions in sleep inertia [45], and that musical elements such as melody results in reduced sleep inertia compared to rhythm. Furthermore, melodic music in particular was found to significantly improve performance on behavioural tests requiring attention when compared to non-melodic alarm designs [46]. In summary, empirical results from both emergency and non-emergency research fields indicate that auditory countermeasures for sleep inertia can be effective, with some treatments including melodic alarms showing significant benefits in reducing sleep inertia (Figure 1).

Stimuli Treatments and Age Demographics

Current research has shown that specific audio treatments such as sequenced low-frequencies, voice notifications, and saliently melodic compositions may be more effective than high-pitched alarms or non-melodic compositions, although there is a need for more research in this field, particularly with respect to age demographics and how findings may translate to different work practices. For example, current research indicates that an alarm design employing a Temporal three alarm (T-3; 500 Hz square wave

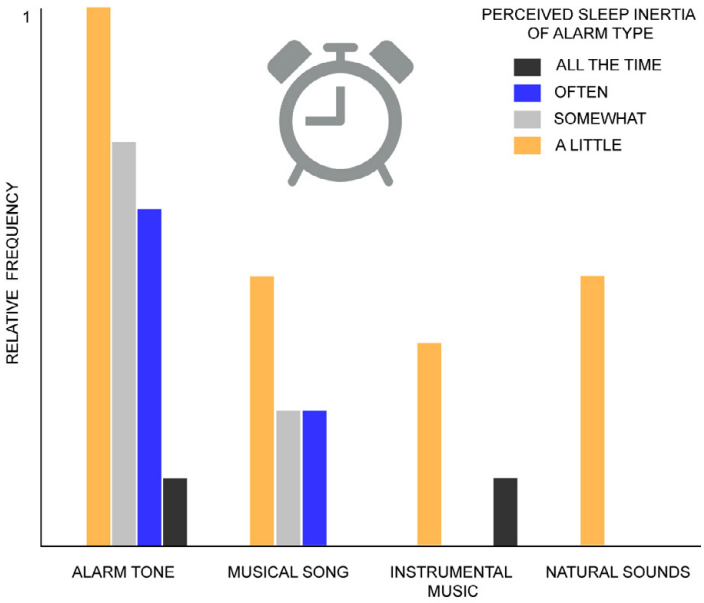

Figure 1: Relative frequencies of alarm sound type and perceived sleep inertia. 'Alarm tone' signifies traditional 'beep beep' styles of alarm sounds. Musical song defines melodic music that may be readily sung along with or hummed too. Instrumental music lacks the vocal component of 'musical song' and may traverse genres such as classical or hip hop. Whilst natural sounds may include birds chirping at the window or running water in a stream.

frequency) [47] and voice notifications (i.e. Maternal, Actor, Male, Female) are superior in counteracting the effects of sleep inertia in children following abrupt awakenings than alarms with higher frequencies (e.g. ~ 2000 Hz - 4000 Hz; Pulsed or Sequenced). A T-3 signal specifies the timing sequence of sound events though not the frequency or timbre [47]. In a repeating sequence, one complete T-3 cycle stipulates a signal must be sounded on for 0.5 seconds, off for 0.5 seconds, on for 0.5 seconds, off for 0.5 seconds, on for 0.5 seconds, and off for 1.5 seconds.

In adults, a high-frequency 'pulse' alarm (2000 - 4000 Hz; ~60 dB) has been shown to be successful in awakening participants and reducing symptoms of sleep inertia regardless of sleep stage at awakening, compared to pre-sleep baseline readings [37]. However, to date, there are no experimental comparisons with different signal designs and controls as those tested with children, and so the most appropriate alarm in a particular context is yet to be resolved. Between children and adult awakenings, there was reported to be no significant difference between demographics in post-awakening RT performance when responding to a high-frequency alarm [38]. However, due to low statistical power within initial studies, further research is required to critically test how findings may translate to specific sectors that may be influenced by auditory alarms.

The possibility of different alarm designs being successful countermeasures for sleep inertia appears strong due to evidence from several studies. Musical treatments have demonstrated significant positive results as a countermeasure for sleep inertia in non-emergency adult awakenings [45,46-48]. The perceived melodicity of a waking alarm chose by a participant shows a significant relationship to reductions in subjectively measured sleep inertia [45]. Preference for popular music and stimuli with melodic features have been shown to counteract sleep inertia in RT and sustained attention [46,48], and that neutral and rhythmic treatments are less effective when compared to melodicity [46].

In summary, for children awakening in emergency conditions, a low-pitch alarm or voice notifications appears to be more effective in counteracting the effects of sleep inertia than alarms with higher frequencies, particularly in memory and RT. For adults abruptly awakened, there is currently insufficient evidence to support firm conclusions regarding the best alarm types and voice signals concerning sleep inertia post-awakening. Optimistic results have been found in non-emergency awakenings with respect to musical treatments in adults, particularly preferred popular music, and alarms with melodic qualities.

Benefits of Auditory Countermeasures for Sleep Inertia - Closing

The primary benefit for the implementation of auditory countermeasures is that digital audio transfer is easily accessible and affordable. Having the ability to download a specific and context-driven alarm sequence on demand prior to the next day's awakening is plausible. Indeed, real-time data monitoring devices such as wearables and dedicated apps are rapidly improving, so that one day they may be used to predict the awakening sound dependant on an individual's own data and schedule. Refining our knowledge of auditory effects on sleep inertia is important to consider, especially where humans are required to pay attention upon and shortly after awakening. In the future, auditory countermeasures may be beneficial for semi-autonomous vehicle control and the effects on 'take-over time' [49]. Further still, human space exploration may one day employ auditory ecologies that mediate human performance to minimize risk and maximise

well-being when key workers have to awaken to make time sensitive and accurate decisions at short notice.

The current empirical evidence observed in this field of research reflects positively on the potential for sound and music to counteract sleep inertia. Notably, there are identified opportunities to capitalize upon, that in turn will strengthen the knowledge base in this field. These include increasing research efforts in adult emergency awakenings with different stimulus treatments and work contexts, comparing treatments between demographics, and further exploring musical treatments in children/adult and emergency conditions. For now, the awakening futures sound positive!

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CONFLICTS OF INTEREST

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