Auditory Binaural Beats Stimulation on Working Memory Functions of Adult and Aging Groups: A Literature Review

การกระตุ้นด้วยคลื่นเสียงไบนอรอลที่ส่งผลต่อทักษะความจำด้านใช้งานของกลุ่มผู้ใหญ่และผู้สูงอายุ: การทบทวนวรรณกรรม

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Abstract

Advancing age is associated with various changes in cognitive capacities, including a decline in working memory functioning (WMF) and some aspects of attention. There has been a growing interest in the use of auditory binaural beats (BB) stimulation for a wide array of applications, ranging from investigating behavioral changes to treating certain health conditions. BB is an auditory illusion perceived when two slightly different frequencies are played separately into each ear. This phenomenon is believed to influence brainwave activity and has been studied for its potential effects on various health aspects. A significant portion of research and application surrounding BB stimulation predominantly explores its psychological effects, with limited attention given to its cognitive implications for individuals susceptible to cognitive decline or impairments. This article aims to review the current body of literature regarding the study of BB stimulation in Western nations, the effects of BB stimulation, the mechanisms underlying BB stimulation and its applications, factors affecting the effectiveness of BB stimulation, the study of BB stimulation within the context of Thailand, and the implications for nursing research and practice. This article brings to the forefront the potential influences of BBs stimulation on the cognitive-behavioral parameters of WMF and attention. The differences in study designs and applications of BBs stimulation and its parameters (e.g., oscillatory bands, frequency range, and stimulation durations), in addition to

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individual characteristics, can yield different results. Understanding their differential effects and factors associated with the BBs stimulation will enable optimal translation and integration of these modalities to effectively address individual needs and maximize therapeutic outcomes. This knowledge will serve as a guideline for nursing and other allied healthcare professionals, policymakers, and academics in their efforts to improve cognitive performance and potentially delay cognitive decline in later life.

Keywords: auditory stimulation, attention, binaural beats, cognitive function, working memory

บทคัดย่อ

การมีอายุที่มากขึ้นมีความเกี่ยวข้องกับการเปลี่ยนแปลงต่าง ๆ ด้านความสามารถในการรับรู้ รวมถึงการทำงานที่ลดลงของความจำด้านใช้งาน (Working Memory Functioning: WMF) และด้านสมาธิบางประการ ในปัจจุบันการกระตุ้นด้วยคลื่นเสียงไบนอรอล (Binaural Beats: BB) เริ่มได้รับความสนใจและถูกนำไปประยุกต์ใช้งานอย่างแพร่หลาย ซึ่งช่วยให้เกิดการเปลี่ยนแปลงทางพฤติกรรมและส่งผลต่อการรักษาภาวะสุขภาพ คลื่นเสียงไบนอรอลเป็นเสียงลวงหูที่เกิดจากความถี่เสียงที่แตกต่างกันเพียงเล็กน้อยที่หูแต่ละข้างได้ยิน โดยปรากฏการณ์นี้ส่งผลต่อการทำงานของคลื่นสมอง ซึ่งมีการศึกษาถึงศักยภาพที่อาจส่งผลต่อสุขภาพด้านต่าง ๆ การวิจัยและการประยุกต์ใช้การกระตุ้นด้วยคลื่นเสียงไบนอรอล ส่วนใหญ่พบว่าเป็นการศึกษาผลลัพธ์ด้านจิตใจมากกว่าด้านการรับรู้ในผู้ที่มีความเสี่ยงต่อภาวะเสื่อมถอยหรือบกพร่องทางการรับรู้ บทความนี้มีวัตถุประสงค์เพื่อทบทวนวรรณกรรมที่มีอยู่ในปัจจุบันเกี่ยวกับการศึกษาการกระตุ้นด้วยคลื่นเสียงไบนอรอลในประเทศฝั่งตะวันตก ผลลัพธ์ของการกระตุ้นด้วยคลื่นเสียงไบนอรอล กลไกภายใต้การกระตุ้นด้วยคลื่นเสียงไบนอรอลและการนำไปใช้ ปัจจัยที่มีผลต่อประสิทธิภาพของการกระตุ้นด้วยคลื่นเสียงไบนอรอล การศึกษาการกระตุ้นด้วยคลื่นเสียงไบนอรอลภายในบริบทของประเทศไทย และผลกระทบที่มีความสำคัญต่อการวิจัยและการปฏิบัติทางการพยาบาล บทความนี้นำเสนอศักยภาพของการกระตุ้นด้วยคลื่นเสียงไบนอรอลที่มีต่อมิติด้านการรับรู้และพฤติกรรมของทักษะความจำด้านใช้งานและด้านสมาธิ ความแตกต่างในการออกแบบและการประยุกต์ใช้การกระตุ้นด้วยคลื่นเสียงไบนอรอล และการตั้งค่าพารามิเตอร์ต่าง ๆ เช่น ช่วงสัญญาณ ช่วงความถี่ และระยะเวลาการกระตุ้น รวมถึงคุณลักษณะเฉพาะของแต่ละบุคคลนั้น ส่งผลให้เกิดผลลัพธ์ที่แตกต่างกัน การเข้าใจถึงผลกระทบและปัจจัยที่เกี่ยวข้องกับการกระตุ้นด้วยคลื่นเสียงไบนอรอลจะช่วยให้สามารถนำไปใช้และบูรณาการวิธีการเหล่านี้ได้อย่างเหมาะสมยิ่งขึ้น เพื่อตอบสนองความต้องการของแต่ละบุคคลได้อย่างมีประสิทธิภาพและทำให้เกิดผลลัพธ์ด้านการรักษามากที่สุด ความรู้นี้จะใช้เป็นแนวทางสำหรับพยาบาลและผู้เชี่ยวชาญด้านการดูแลสุขภาพ ผู้กำหนดนโยบาย และนักวิชาการที่มีความพยายามในการฟื้นฟูทักษะการรับรู้และศักยภาพที่จะช่วยชะลอความเสื่อมถอยของทักษะนี้ในช่วงชีวิตบั้นปลาย

คำสำคัญ: การกระตุ้นด้วยการฟัง สมาธิ คลื่นเสียงไบนอรอล การรับรู้ ความจำด้านใช้งาน

Introduction

Advancing age is associated with a variety of changes in cognitive capacities, including a decline in working memory functioning (WMF) and some aspects of attention. Previous empirical studies have shown that age-related cognitive decline is evident in tasks necessitating a quickly process or transform information to make a decision, including measures of WMF[1,2] and speed of processing.[3,4] WMF is critical for multiple aspects of cognition, providing temporary storage and manipulation of information necessary for complex tasks.[5] Though changes in attention in old age are not fully understood, sustained attention or vigilance is particularly affected with advancing age. Sustained attention refers to the ability to retain the focus of attention on a task or stimulus over extended periods.[6] It is broadly agreed that working memory is closely linked to attention, leading to the constitution of two important cognitive skills.[7,8]

The increase of chronological age is widely recognized as the primary risk factor for cognitive function decline and changes in neurological conditions. Studies have revealed that around 40% of individuals aged 65 years or older experience some degree of memory loss, often progressing to progressive neurological conditions such as Alzheimer's disease.[9-11] Additionally, research indicates that mild cognitive impairment (MCI) affects roughly 16% of individuals over 70 years old, while approximately 14% of people in the same age group suffer from dementia.[12-14]

This article aims to review the current body of literature regarding the study of BB stimulation in Western nations, the effects of BB stimulation on the working memory functions (WMF) and attention of adults and older adults, the mechanisms underlying BB stimulation and its applications, factors affecting the effectiveness of BB stimulation, the study of BB stimulation within the context of Thailand, and the implications for nursing research and practice.

Literature review

A literature review can provide a diverse array of evidence. This process typically involves two main steps: the formulation of a search strategy and the subsequent summary of the results, which encompasses the characteristics of interventions and their corresponding outcomes.

The Study of BB Stimulation in Western Nations

A comprehensive review of the literature examining the most current applications of auditory BB stimulation on cognitive-behavioral parameters of working memory and attention

was adopted. Searches were conducted in the following bibliographic databases: Medline (1946 - present), EMBASE (1974 - present), PsycINFO (1806 - present) via OVID; Cumulative Index for Nursing and Allied Health Literature (CINAHL, 1936 - present) via EBSCOhost; Scopus (1976 - present) via Elsevier; Web of Science (all databases inception - present); and Cochrane Library via Wiley (1992 - present). A critical perspective, insights, and recommendations for further research and practice were also provided.

Effects of BB Stimulation

Research on the effects of BB stimulation on individuals has gained considerable attention after being studied and described by Licklider and colleagues.[15] This is particularly due to its ability to affect behavioral changes,[16] promote relaxation, meditative states, and sleep cycles,[17] and treat various conditions such as anxiety, learning disorders, and pain.[18-21] A study by Chuan Sung and colleagues[22] found that a noninvasive binaural beats intervention contributed significantly to reduce heart rate, blood pressure, and depression level of older people residing in long-term care settings. In addition, a novel auditory stimulus that combines BB and autonomous sensory meridian response (ASMR) has been found to improve the quality of sleep and emotional states.[23] A recent study by Tani and colleagues[24] reveals that BB intervention can reduce post- operative morphine consumption among older patients undergoing knee replacement.

Music intervention has been extensively studied and shown to have positive effects on cognitive function, emotional well-being, and quality of life, encompassing a broad range of activities and therapeutic tools.[25] Research revealed that the BB intervention is being introduced as a novel potential cognitive enhancer that entrains the brain and modulates brain activity, leading to the manipulation of certain cognitive functions such as working memory or attention.[26-28] Nevertheless, much of the research focuses largely on the psychological effects of BB stimulation and merely covers a very small portion of this vast field of research.

The Mechanisms Underlying BB Stimulation and Its Applications

Overall, the brain's response to BB can be measured by Electroencephalography (EEG), yet the exact mechanism of BB is not yet known.[29] The theoretical basis of the effects of BB stimulation is the brainwave entrainment hypothesis, which suggests that external stimulation at a certain frequency leads the brain's electrocortical activity to oscillate.[29] In fact, exposure to BB has been shown to induce synchronization of the brain hemispheres, suggesting that beat stimulation alters intracranial EEG characteristics.[29] The application of BB

stimulation resembles listening to specific audio files that usually contain music or nature sound.[30] These recordings are augmented with specific tones and frequencies designed to modulate brainwave activity, thereby enhancing listeners' ability to focus. This technique, known as auditory BB stimulation, utilizes rhythmic auditory stimuli to elicit a frequency-following brainwave response.[30]

Binaural beats (BB) are a perception of sound generated within the brain, occurring as the two almost equivalent pure tones of slightly different frequencies are presented simultaneously to each ear. The sound presented to each ear is processed individually, leading to a perceived single sound consisting of the frequency that is difference in hertz (Hz) between the frequencies of the two tones.[31] For example, if the right ear registers a tone at 120 Hz and the left ear registers one at 130 Hz, the binaural beat is 10 Hz — the difference between the two frequencies. In BB perception, the tones entering the left and right ear should be at frequencies lower than 1,000 hertz (Hz) for the brain to detect and generate BB.[32]

The oscillatory frequency bands have been linked to a range of cognitive processes, emotional states, and behaviors.[31] Specifically, studies focusing on cognitive abilities such as memory and attention utilize alpha, beta, theta, and gamma binaural beats.[17] Alpha oscillations are relatively associated with cognitive task- related working memory.[33] According to Klimesch,[34] theta waves play a vital role in new information processing, beta waves relate to cognitive control, while gamma waves contribute to perceptual and cognitive processes, especially on attention performance. Alekseichuk and colleagues[35] stated that an improvement in working memory was significantly evident when high oscillatory gamma frequency was combined with increased theta waves. Although these oscillatory frequency bands (i.e., alpha, theta, beta, gamma) seem to alter cognitive functioning, a question pertaining to which frequency range and conditions can exert a better effect on memory and attention, remains a challenge or unclear.[34]

Evidence suggests that brain activity within alpha frequency (7-11 Hz) has been associated with cognitive functioning in adults such as vigilance, working memory, attention, and information processing.[26-28] A study of Kraus and Porubanovà[26] revealed that the oscillations in alpha rhythm (9.55 Hz) at the stimulation duration of 12 minutes have been associated with an increase in the cognitive capacity of working memory of healthy adults. Similar findings are documented in a study by McMurray,[27] examining the effects of BB on the cognitive capacities of older adults aged over 65. In this same study, the author found that older participants showed a significantly higher memory function during the BB stimulation with alpha frequency range at 7 and 11 Hz.[27] In addition, Solcà and colleagues[28] proposed that

alpha frequency BB (10 Hz) is associated with improved attention performance of adults, particularly on the vigilance task.

Table 1 The summary of BB stimulation on cognitive functions

Reference No.	The Oscillatory Bands	Frequency Range (Hz)	Entrainment Duration (Minutes)/Session	Main Findings
26-28	Alpha	7-11	4-12	The music embedded with BB contribute significantly to improve working memory and attention functions, especially on the vigilance task.
31, 36-37	Beta	15-24	5-30	Positive effects were found on cognitive-related task, including visuospatial, working memory, free recall and recognition, and vigilance and concentration.
38-39	Theta	5-5.5	15-36	Participants showed a significantly higher memory and recall functions during the BB stimulation.
40-44	Gamma	40	3-15	The BB intervention contributes to enhance divergent thinking, promote cognitive flexibility, and improve attentional focus.

Several studies suggest that an improvement in attention and memory is accompanied by a beta frequency band at 15-24 Hz. Beauchene and colleagues[36] examined cognitive performances using beta-frequency (15 Hz) BBs intervention on healthy adults and found a significant improvement on visuospatial and working memory tasks of the sample. A recent study of Garcia-Argibay and colleagues[31] found that the BB intervention with beta (20 Hz) frequency range contributes to an increase in free recall and recognition tasks, enhancing long-term memory. Lane and colleagues[37] suggested in their research findings that a higher vigilance and concentration were related to the beta (16-24 Hz) frequency range, particularly when exposed to 30 minutes of BB intervention over 3 days.

A few studies investigated the effects of theta frequency band on the cognitive capacities of individuals. Roberts and colleagues[38] revealed that exposure to theta entrainment (5.5 Hz) leads to an enhancement of memory performance. Similar findings were found in a study by Ortiz and colleagues,[39] examining the influence of auditory theta BB stimulation on recall memory. The authors found that theta frequency BB stimulation (5 Hz) can help to improve recall memory.[39] A frequency of gamma BB at 40 Hz has been found to improve divergent thinking and promote cognitive flexibility,[40,41] enhance the focus of attention,[42] accelerate attentional focus outcomes,[43] and increase the efficiency of attention processing.[44] Based on the review, a summary of the specific oscillatory frequency bands on cognitive abilities or cognitive functions, particularly about memory and attention is illustrated in Table 1.

Factors Affecting the Effectiveness of BB Stimulation

The use of BB stimulation as an intervention is believed to induce beneficial alterations in brainwave patterns, resulting in diverse states of relaxation and corresponding changes in cognitive functions. Findings from a study by Basu and Banerjee[33] attributes the positive effects of the BB stimulation on memory and attention, to variation in the factors such as using alpha frequency only entrainment, beta frequency as the masking noise, BB entrainment given before-after the task or between encoding and retrieval, or during the task.

Nonetheless, several studies highlighted challenges and factors that influence the efficacy of BB stimulation, rendering mixed and conflicting results.[17,45,46] These may in part due to individual variability, study design and intensity parameters, background noise and environment, duration and timing of exposure.[20] For example, McMurray[27] identified personal characteristics, such as age-related changes in hearing, as a significant challenge that impacts the efficacy of BB stimulation in older adults. Some studies failed to demonstrate the effects of BB stimulation on cognitive ability, in particular attention. Crespo and colleagues,[17] for example, conducted a randomized controlled exploratory pilot to investigate the effects of theta (4 Hz) and beta (16 Hz) BB stimulation on participants' attention. The authors reported no significant improvement on cognitive function partly due to several factors such as short duration of BB stimulation, small sample size, and inappropriate cognitive task assessments.[20] A study by Goodin and colleagues[45] examined the effect of theta (7 Hz) and beta (16 Hz) BB stimulation on the vigilance task, with a total entrainment duration of 4 minutes. In this same study, the authors revealed no significant changes in cognitive performance and concluded that the short presentation of BB stimulation was insufficient to alter vigilance.[45] In addition, Robinson and colleagues[46] examined the effect of BB stimulation on sustained attention using

a beta frequency beat (16 Hz). The authors reported no evidence for such effects, noting several factors including a narrow focus on a single frequency band and limitations in the comparison conditions.

With regard to the contextual viewpoint, the integration of BB stimulation has been explored in diverse contexts, both in clinical and non-clinical settings. Research suggests that creating a conducive environment that prioritizes comfort, relaxation, and safety can optimize the effectiveness of BB stimulation and promote positive outcomes for individuals undergoing the intervention. The presence of background noise or an unsuitable environment may interfere with the ability to perceive BB or disrupt the desired outcomes.[47] In addition, to optimize the benefits of BB stimulation, it is essential to utilize high-quality headphones to ensure the clear and accurate delivery of the intended BB frequencies. A poor quality of audio equipment has the potential to distort frequencies, thereby diminishing the effectiveness of BB stimulation.[44]

The Study of BB Stimulation in Thailand

In Thailand, while research specific to BB stimulation is limited compared to other regions, the concept of using sound and music as a complementary approach has deep roots in Thai culture. The relatively low adoption and application of BB stimulation as a non-pharmacological intervention for enhancing overall health and well-being may be hindered by various factors.[48,49] These may be in part due to limited financial resources, insufficient research and resources, disparities in access to BB technology, lack of awareness and cultural acceptance.

In recent years, with growing interest in alternative and complementary therapies, including those involving sound and music, BB stimulation has likely captured the interest of researchers, clinicians, and individuals seeking non-pharmacological approaches to enhance several aspects of health. A recent study by Wichian and colleagues[48] examined the effects of music embedded with BB on physiological responses and anxiety levels of Thai adults and older people. The authors found that the BB group has a significant decrease in blood pressure, respiratory rate, heart rate, and anxiety scores. Similar findings are found in a study by Opartpunyasarn and colleagues,[49] investigating the effects of BB stimulation on the preoperative anxiety of Thai patients undergoing fiberoptic bronchoscopy. In this study, the authors noted that music with BB effectively reduced anxiety levels and blood pressure compared with the plain and no music interventions.

Given Thailand's cultural heritage and openness to holistic health practices, it is possible that BB stimulation could be embraced and incorporated into various health and

wellness practices and interventions. Further exploration and research in this area could offer valuable insights into the potential benefits and uses of BB stimulation within the Thai context.

Implications for Nursing Research and Practice

While there has been growing evidence on the effects of BB stimulation, studies focusing on cognitive-related tasks such as memory and attention are notably scarce, especially within the realms of clinical practice and research in less economically developed regions. The findings from this article are in line with the previous studies that the auditory BB intervention has a positive influence on the cognitive domains.[20,26,27] Although a few studies reported no significant differences in cognitive performance, most of the studies[31,36,37] included in the present review reported positive results. This highlights the need for more systematic investigation.

Most existing studies involved a sample of healthy adults, with one study comprised of older people. A study by McMurray,[27] for instance, examined the effects of BB intervention on cognitive-related tasks of older adults aged 65 and over. The author reported that a higher memory function is associated with BB stimulation.[27] Since there are limited studies that have investigated the effect of BB intervention on older participants' cognitive abilities, further research is needed to explore and provide a better understanding of the potential influence of BB stimulation. This knowledge may serve as a guideline for healthcare professionals including nurses, physicians, policymakers, and scholars in their efforts to improve cognitive performance and potentially delay cognitive decline in older people.

The auditory BB has been proven to be a non-pharmacological and safe intervention,[33] a better understanding and utilizing the BB approach in the care of adult and aging populations may enhance or facilitate medical treatment and rehabilitation. Additionally, given that auditory BB stimulation has already been tested with healthy participants, investigating its possible effects on patients with mild cognitive impairments may have the potential for clinical impacts in Alzheimer's disease and other cognitive-related disorders.[33]

While the potential benefits of BB stimulation in nursing practice are considerable, it is crucial to acknowledge challenges such as individual differences in response and the lack of standardized protocol. Further research is warranted to establish optimal parameters of BB stimulation for diverse groups and its long-term effects on cognitive functions. Moreover, the differences in study designs and applications of BB and its parameters (e.g., frequency bands, carrier frequencies, entrainment durations, control conditions, in addition to individual characteristics, can yield different results.[20] Inconclusive and negative results could possibly be attributed to the variation of factors, including the selection of inappropriate frequency

bands for the wrong cognitive tasks. A more concerted research effort using larger samples to explore the dominant frequency ranges and bands against a control stimulus in various aspects of cognitive performance is critical. The establishment of guidelines for practical application, taking into account safety measures and evidence-based practices, is a significant consideration to guide healthcare professionals, researchers, and practitioners effectively. This may lead to a comprehensive understanding of the BB stimulation and its parameters, providing imperative implications in both clinical and non-clinical settings.

In the context of nursing practice, nurses can play a pivotal role in developing individualized care plan that incorporates BB stimulation as a non-pharmacological intervention for the individuals based on their specific needs, musical preferences, clinical indications, and overall goal of care. In addition, nurses can collaborate with other healthcare professionals, such as psychologists, therapists, and technologists, to develop comprehensive care plans that include BB stimulation alongside other therapeutic modalities. This interdisciplinary approach can tailor interventions to meet the individual unique needs and ensures they receive holistic care that addresses physical, emotional, and cognitive well-being effectively. Further, nurses can provide education to the individuals and their families about BB stimulation, including how it works, potential benefits, and safety considerations. Nurses can offer guidance and support to facilitate individuals' engagement and adherence to the BB intervention.

Conclusion

This article highlights the multifaceted potential of Binaural Beats (BB) stimulation in nursing and healthcare practice, focusing on its cognitive effects and implications for adult and aging groups. The findings reveal the promising role of BB stimulation in enhancing cognitive functions such as attention and memory. While the evidence suggests positive outcomes, it is essential to acknowledge the existing challenges and methodological considerations. The integration of BB stimulation can serve as an innovative and non-invasive adjunct to conventional nursing interventions. By incorporating these BB interventions tailored to individual patient characteristics, nursing professionals have the opportunity to enhance cognitive performance, mitigate cognitive decline, and contribute to overall patient well-being.

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