Journal of Health Care and Research
(ISSN: 2582-8967)
Commentary
DOI: https://doi.org/10.36502/2025/hcr.6241

# Recent Trends for Auditory-Motor Synchronization (AMS) and Related Development

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**Received date**: 19 January 2025; **Accepted date**: 15 February 2025; **Published date**: 22 February 2025

**Citation:** Bando H, Yoshioka A, Nishikiori Y. Recent Trends for Auditory-Motor Synchronization (AMS) and Related Development. J Health Care and Research. 2025 Feb 22;6(1):12-15.



## Abstract

Auditory-Motor Synchronization (AMS) has recently attracted attention. It coordinates motor actions with rhythmic auditory stimuli, applying to dancing, running, playing music, communicating, and conversations. Several brain regions are involved in this mechanism, such as the primary motor cortex (M1), supplementary motor area (SMA), premotor area (PMA), and basal ganglia. Temporal prediction and timing control are necessary for AMS execution. Medical applications include Parkinson's disease (PD) and stroke cases for rhythmic auditory stimulation (RAS). Future developments in collaboration with artificial intelligence (AI) are expected. AI can learn human AMS patterns and allow robots to synchronize similar movements with more natural micro-movements.

## Keywords

Auditory-Motor Synchronization, Primary Motor Cortex, Intrinsic Clock, Rhythmic Auditory Stimulation, Artificial Intelligence

## Abbreviations

AMS: Auditory-Motor Synchronization; M1: Primary Motor Cortex; RAS: Rhythmic Auditory Stimulation; AI: Artificial Intelligence

## Commentary

In recent years, the choice of medical treatment for middle-aged and elderly people has become more widespread. Complementary and alternative medicine (CAM) is also known, and instead of immediately resorting to drug therapy, methods that make effective use of music and exercise are attracting attention. The authors have traditionally managed the CAM society and continued research into music therapy, physical therapy, art therapy, dance therapy, psychosomatic medicine, and other fields [1]. In this article, we would like to touch on recent trends in Auditory-Motor Synchronization (AMS) [2].

AMS refers to the ability to coordinate motor actions with a rhythmic auditory stimulus. It is a fundamental human skill crucial for dancing, playing music, communicating, and engaging in conversations [3]. Some examples are as follows: i) Dancing – synchronizing whole-body movements simultaneously to the beat of music [4], ii) Finger tapping – tapping fingers, hands, or feet to the beat of music [5], iii) Running – synchronizing running steps to the beat of an auditory metronome, and iv) Playing an instrument – playing musical instruments in time with the beat.

Several factors influence the degree of AMS. People with years of musical training tend to exhibit better AMS function than those without training [6]. Specific movements, such as finger tapping, may synchronize better with discrete auditory rhythms. The acoustic features of the stimulus, like tempo, can influence how well someone synchronizes to a satisfactory degree. Different individuals may possess varying levels of AMS depending on the situation. Thus, AMS can be applied to enhance performance in sports, exercise, rehabilitation, and physical movement. For example, acoustic rhythms can be easily used to help runners, joggers, rowers, and cyclists improve their performance.

The mechanism of AMS depends on the integrated function of the human nervous system, which connects hearing and movement [7]. The primary mechanism can be described from a medical perspective. AMS relies on the cooperation between the auditory and motor systems. It operates in a bidirectional manner, involving auditory input and motor output [8]. The auditory system detects sounds through the ears with the organ of Corti, transmitting them to the brain as electrical signals. This process allows for rhythm and tempo information. The motor output then sends commands to muscles based on the rhythm information, synchronizing movements with the sound. This cooperation is regulated by neural circuits connecting hearing and movement.

AMS information is processed in the brain, with each area serving a distinct function [9,10]. The primary auditory cortex (A1), located on the upper side of the temporal lobe, initially processes the frequency and rhythm of sounds. The auditory association cortex is involved in recognizing sound patterns and tempo. Motor control involves three key areas: i) The primary motor cortex (M1) – directly commands muscle movements, ii) The supplementary motor area (SMA) – is involved in planning movements and predicting rhythm, and iii) The premotor area (PMA) – helps plan movements based on external rhythms.

Auditory-motor integration involves three additional areas: i) The parietal lobe – crucial for integrating sensory input related to hearing and movement, ii) The cerebellum – supports precise adjustments of rhythm and timing, and iii) The basal ganglia – plays a vital role in predicting patterns and adjusting the timing of movements, essential for rhythmic actions. Based on various studies, brain functions related to AMS are summarized in **Fig-1** [5]. Multiple brain regions work together to perform AMS functions [11].

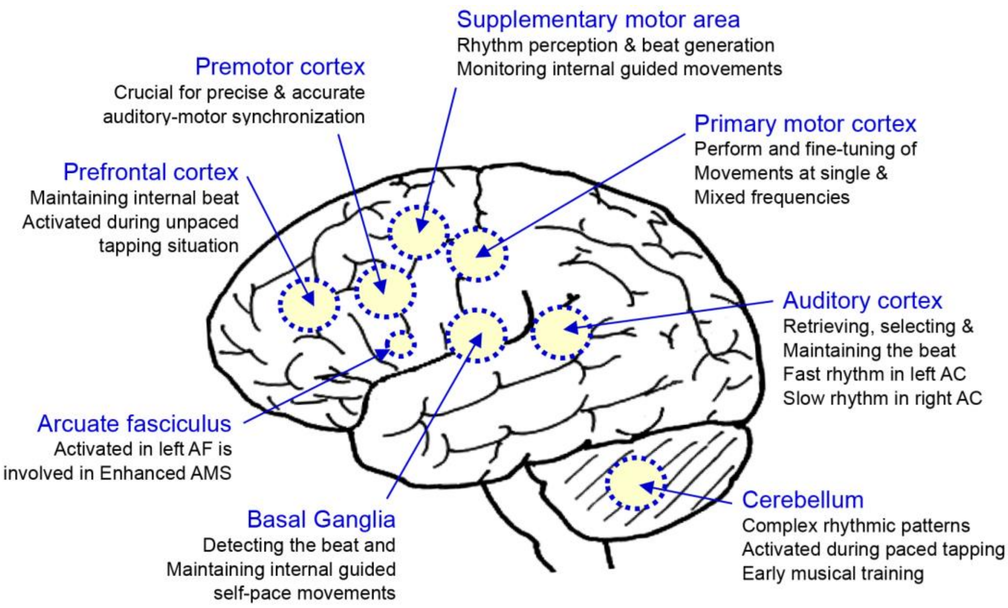


**Fig-1: Key Brain Regions for Auditory–Motor Synchronization (AMS)**

For AMS execution, temporal prediction and timing control are necessary. Temporal prediction refers to the ability to recognize rhythm and beat patterns and predict future timing. This process is supported by the basal ganglia and cerebellum. The brain has an "intrinsic clock" that enables motor control to follow a certain rhythm [12], with the cerebellum playing a key role. Furthermore, adequate control of both feedforward and feedback mechanisms is required. Feedforward control allows predictive adjustments based on auditory stimuli, enabling a person to move without falling behind the rhythm [13]. Feedback control, based on sensory input, ensures that actual movements stay in sync with the rhythm and allows for necessary corrections.

The clinical significance of AMS is evident in three common diseases. In Parkinson's disease (PD), decreased basal ganglia function leads to impaired rhythmic movements [13]. However, patients can improve movement by using a metronome, music, or clapping with a regular beat. This phenomenon is a characteristic aspect of PD. For stroke rehabilitation, AMS contributes to restoring gait and motor control. In cases of developmental and language disorders, AMS proves effective for continuous training.

AMS is achieved when multiple brain regions in the auditory and motor systems work together by predicting and adjusting rhythm and timing [14]. AMS has broad potential and is expected to contribute to various fields in the future, including medicine, science, education, entertainment, and artificial intelligence (AI). Some specific applications are described below.

In medicine and rehabilitation, AMS can have clinical benefits for several conditions, including PD and stroke recovery through rhythmic auditory stimulation (RAS) [15], as well as dementia, mild cognitive impairment (MCI), stress relief, anxiety reduction, and support for autism and attention deficit hyperactivity disorder (ADHD). In education, integrating AMS has the potential to enhance learning. In language acquisition, AMS can improve efficiency in learning accents and pronunciation.

Technological advancements and interface development will further expand AMS applications. Innovations may include linking music and movement, virtual rehabilitation using virtual reality (VR), real-time monitoring of exercise and health habits with feedback, and music-image interfaces. Collaboration with AI is also anticipated. In human-machine interaction, AI can learn human AMS patterns and enable robots to synchronize movements with more natural micro-movements. In the future, interfaces based on AMS brain activity may allow synchronization of movements and brainwaves with music and external devices.

In summary, AMS has been described from multiple perspectives, including its fundamental mechanisms and medical applications. As technology advances, the integration of AMS and AI is expected to promote human health, well-being, and happiness worldwide.

## Conflict of Interest

The authors have read and approved the final version of the manuscript. The authors have no conflicts of interest to declare.

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