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Review Article

Mirror Neurons and Imitation Learning in Early Motor Development

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ABSTRACT

The paper reviews research on imitation learning. The development of the nervous system is a reciprocal process where the neural networks are formed as a result of motor action produced by the individual. Review research further shows that plasticity is an important quality of the brain that helps in the formation of neural structures based on the individual's interaction with the environment where imitation is an important learning mechanism. A review of literature shows that the human mirror neuron system (hMNS) is involved in imitation learning and motor imagery. The research review comes to the conclusion that the development of hMNS is a significant factor in facilitating imitation learning. Stimuli from the environment and the adequate response from the nervous system are crucial factors for the proper development of the central nervous system. This makes the development of hMNS and the development of movements' reciprocative process.

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INTRODUCTION

Development of motor ability is an indispensable aspect of growth and development of any living organism. Motor quality of a living organism is closely related to other structural and functional developments that take place in the organism simultaneously.[1] Motor development of a child is a result of a combination of changes that take place in the individual. Changes in neural structure and function play a crucial role in motor development. Children become involved in a variety of fundamental motor activities that are an integral part of their behavioral repertoires and provide the opportunity through which they interact with their environment, especially during the early years of their development.[2] One of the most important methods through which infants and children learn movements is imitation. Imitation of action is a fundamental cognitive ability that helps in acquiring a variety of skills in an effective manner.[3] Newborn babies are capable of imitating the actions of elders. In the 1st year of life, babies are capable of acquiring a wide range of actions on objects through imitative learning.[4-6] In a seminal study conducted on 14-month old babies, it was found that 67% of babies were capable of imitating a novel task performed by a human model after a delay of 1 week.[7] The human infants are prolific imitators, and the researchers argue that this mechanism of observation-execution is present even before the development of language or any other form of learning.[3] Their statement is based on the results derived from Mu rhythm (a sensorimotor brain rhythm in the Alpha band) suppression recorded using electroencephalogram in the infants while they observed and imitated actions. Infants observe the actions of other social agents to learn and perform their actions. However, whether these imitations represent later social cognition are matter further investigation.[8] The ability of an individual to connect the visual representation of an observed action with the motor representation of that action could lead to imitative learning.[9] When one observes actions of others, it helps to develop the image of oneself doing the same action in the observer's mind.[10] There are three prominent theories in relation to infant imitation. One argument is that neonatal imitation is an abstract representation of social communication. The second argument states that it is an involuntary reflex and the third argument states that it is a product of arousal.[11] The internal stimulation or motor imagery might play a critical role in imitation learning or the ability to understand other individuals' movements.[12] This mechanism of imagery is widely used in learning and performing motor skills.[13] Neuroimaging and experimental studies have provided evidence that several common neural areas are involved in the actual movement, imagery of that

movement, and observation and imitation of that movement done by others.[14-18] The neural mechanisms involved in learning by seeing (imitation) are similar to learning by doing.[19-22] Hence, it is proposed that exposure to opportunities to observe movements and encouragement to imitate those movements will enhance the motor development of children.

METHODOLOGICAL APPROACHES

The purpose of this paper is to review the research literature relevant to the role of mirror neurons on imitation learning at the early stage of motor development. To start with the paper will define major concepts involved in the core discussion. The paper will further adopt a methodology that will discuss research on imitation learning focusing on infant imitation and human mirror neuron system (hMNS) and its development in human beings.

DEFINITIONS

The following definitions will help in understanding the process and content of motor development. Motor development is a process by which a child acquires movement patterns and skills.[2] Another definition cut out motor development as changes in motor behavior which reflects the interaction of the maturing organism and its environment.[23] It was also defined as the change in motor behavior across the lifespan. Clark and Whittal further stated that motor development contains both change in the performance and the mechanism of change underlying motor development as the individual grows.[24] A more elaborate definition from the dynamic system perspective defined motor development as a process of changes in human motor behavior that reflects a dynamical interaction between the maturing organism, the environment, and the task.[25-27] Magill defined motor development as the study of human development from infancy to old age with a specific interest in issues related to either motor learning or motor control.[28] All these definitions are congruous in agreeing that individual, environment, and task are the most important elements that determine motor development. The interaction among these three elements and the resultant changes during the life an organism determines the kind of motor development an organism undergoes. A thorough understanding of imitation learning is essential before engaging in a discussion on research in imitation learning. In 1898, Thorndike defined imitation as any situation in which animals "from an act witnessed learn to do an act." The process of learning to do an act by seeing it done is known as imitative learning.[29] Another definition defines movement imitation as the copying of a novel or improbable act for which there is no instinctive tendency.[30] Imitation learning refers to an agent's acquisition of skills or behaviors by observing a teacher demonstrating a given task. It is further defined as the process by which an agent uses instances of performed actions to learn a policy that solves a given task.[31] One of the major breakthroughs in brain research in the past two decades is the discovery of mirror neurons. This specialized group of neurons was originally discovered in the premotor cortex of monkeys.[32-34] Rizzolatti, one of the pioneers in mirror neuron research, is defined mirror neurons as a particular type of neuron that is discharged when individuals perform an action, as well as when they observe a similar action done by another individual.[35] One of the earlier definitions, formulated when the mirror neuron system was first discovered in the monkey brain, classified mirror neurons as a class of visuomotor neurons.[32-34] They were originally found in area F5 of the pre-motor cortex of the monkey. Researchers highlighted the ability of these neurons to discharge both when monkeys performed a particular action and when they observed another individual doing a similar action as its major functional characteristic. Iacoboni *et al*. stated that mirror neurons produce a greater response to imitation than to a controlled motor task.[36] They further proposed that response to observation of action is another important characteristic of mirror neurons. According to Goldman mirror neurons are a class of neurons that discharged both when an individual (monkey, human, etc.) underwent a certain mental or cognitive event endogenously and when it observed a sign that another individual underwent or was about to undergo the same type of mental or cognitive event.[37]

Review on imitation learning

The imitation studies used a variety of experimental designs to establish that the learning happens through imitation. Meltoff in a pioneer study conducted an experiment on 14-month-old infants. The infant participants in the experimental group were exposed to the observation of one of six actions which were a novel behavior, but they were prevented from immediate imitation of actions. After a week children were a given chance to imitate previous actions of an adult. The children in the experimental group produced significantly more target actions than infants from the other group.[7] The results of this study provided evidence for infants' ability to imitate and retain the actions of adults. Imitation of index finger protrusion task was investigated, and the participants were 39 neonates using an ethologically based objective coding system. Participants demonstrated imitation of finger movements through an incomplete imitation stage. It was further noticed that imitation was more frequently left-handed. Researchers further provide evidence for neonate imitation with the help of a differential increase of index finger protrusion during the imitation period. This demonstrated that this behavior was not generated by general arousal, but a result of neonatal imitation.[38] A study was conducted to predict social and anxiety-related behaviors at year among infant rhesus macaque. Researchers investigated whether the newborn macaques' capacity to imitate facial gestures and whether this could be used as a viable predictive marker for the onset of socialization in later development stage. The results of the exhibited that neonatal imitation can be early prediction of infants' social development.[39] In a comprehensive study Oostenbroek *et al*. tested the theory of infant imitation. They pointed out that some of fundamental investigations which led to the formation of these theories used cross-sectional designs with small samples and limited controls which could have influenced the results. The longitudinal study that they conducted had 106 infant participants. They used nine social and two non-social models and the response was scored for 1, 3, 6, and 9 weeks of age. The results indicated that the infants did not imitate any of the models. They simply produced some gestures that were similar to control models. They further stated that the previous results could be the effects of mere artifacts of restricted comparison conditions.[40] Meltzoff *et al*.

used the raw data from Oostenbroek *et al*. and conducted an independent analysis and identified 11 important flaws in data analysis conducted by Oostenbroek *et al*. Meltzoff *et al*.'s analysis revealed that there was significant tongue-protrusion imitation in all four groups of 1, 3, 6, and 9-week-old infants.[41] Oostenbroek *et al*. in a reply to Meltzoff *et al*.'s reanalysis of data explained that their aim was not to test the veracity of neonatal imitation. They further stated that more evidence is essential for the propensity to imitate should not be considered an established phenomenon.[42] It should be noted that there were several studies that provided evidence for neonatal imitation and hence the contradictory report from Oostenbroek *et al*. cannot be taken very seriously.[3-6,43-45] Nevertheless, more care should be taken to improve methodological rigor that can lead to quality data which will help in accurate analysis and interpretations. It should also be noted that there are several studies that provided unequivocal evidence for imitation in human beings.[46-50] Moreover, imitation will remain as one of the most important methods of learning.

Review on mirror neurons and motor development

Research has several pieces of evidence that strongly suggest the role of mirror neuron system in motor development based on action observation and imitation paradigm.[15,19-21] An analysis of research on mirror neurons and motor development will help us to understand how the mirror neuron system help in early motor development and how it reflects on imitation of movements. Researchers even go on to suggest that environmental differences provided through sensorimotor training can bring in mirror neuron response patterns making them capable of bringing out the best suitable motor and social responses.[51] A study that tested the influence of motor experience on neural correlates of action understanding among infants suggested that infants might have an experience independent sensorimotor mechanism capable of understanding all coherent motions that are tuned up by experience.[52] Another study that tested the influence of maternal mirroring on visual and motor representation of facial gestures found that maternal mirroring could play a crucial role in increasing the neural sensitivity in early social development.[53] It is further understood that though the mirror neurons exist in the brain at the time of birth, they continue to develop even beyond childhood.[54] One brain location that contains mirror neurons is inferior parietal lobe, where the gray continues to grow even beyond the adolescence through the interaction with the environment including peers.[55] Nystrom *et al*. conducted a study in which they derived evidence for mirror neuron system in 8 month old babies based on mu rhythm suppression. In this study babies observed a goal directed grasping movement which caused mu rhythm suppression and the researchers considered this as an evidence for the existence of mirror neuron system among the 8 month old infants.[56] Lepage and Theoret investigated mu rhythm activity during the execution and observation of a precision grip in children in an age range of 4–11. They found desynchronization to both execution and observation condition in 8–13Hz, frequencies which were similar to the results found in the more matured individuals.[57] These results also confirmed the finding by Marshall *et al*.[58] Although there have been in-depth reviews of research that provided evidence for the existence of mirror neuron system in human beings,[59] there are researchers who questioned the existence of such neural network.

Hickok argues that there is not enough evidence to suggest that there is mirror neuron system exist in human beings. According to him, there is no direct evidence available to establish the existence of such a system that facilitates action observation-execution matching mechanism.[60] Kosonogov stated that there is empirical data that cannot be explained through a mirror neuron model.[61] Hickok raised doubts about the involvement of mirror neurons in action understanding.[62] Although there are a few researchers raising their arguments against mirror neuron phenomenon, the amount of evidence available in support of the existence of hMNS and its involvement in action understanding, imitation, and imagery is far greater than the opposing arguments and cannot be ignored. The evidence for the existence of mirror neuron system even at the time of birth shows that it plays a huge role in human motor development.

Interactive effects of mirror neurons and imitation learning on motor development.

Development of the central nervous system (CNS) is a major developmental function of an organism. CNS development is significant, as far as the development of motor ability is concerned. In itself, nervous system development needs to be analyzed thoroughly to understand the developmental mechanisms associated with the movement. The development of new motor skills is dependent on the changed structure of the nervous system. The change in the structure of the nervous system depends on biological, environmental, and task factors.[63] The plasticity of the brain is an important quality, which helps the development of the nervous system, depending on experience from the environment.[64] Greenough *et al*. further proposed two different types of plasticity based on the nature of information stored resulting from experience. They are "experience-expectant" plasticity and "experience-dependent" plasticity. A mapping study was conducted by Merzenich *et al*. in monkeys. They initially mapped the fingers in the cortex and found that these were represented in accurate topographical order in the cortex. Later they amputated two fingers and found that monkeys learned to replace the use of those fingers using the palm of the hand in making certain movements. Interestingly, Merzenich *et al*. discovered that the space occupied by the amputated fingers in the topographical brain map was taken over by the palm of the hand. This shows that enforced changes in movement pattern can lead to topographical changes in the brain, which is involved in the control of those movements.[65] Provision for proper motor experience is an essential prerequisite for the normal and effective motor development of a child. Deprivation of motor experience can interfere with children's abilities to perform movement tasks characteristic of their age levels.[66] Wong and Gosh stated that neural transmitters and neural activity regulate dendritic motility and dendritic growth.[67] This explains that the receiving signals from the environment through sensory organs through afferent nerves activate the CNS, which, in turn, leads to neural activity and motor actions through efferent motor nerves such as neural transmission and neural activity regulate neural motility and neural growth. The improvement in neural growth and neural

motility will naturally affect effective motor development. This makes the process of nervous system development and motor development a reciprocal process. There are debates on whether the mirror neuron system is a derivation of evolution or the product of associative learning process. Heyes proposes that it is a product of both evolutionary adaptation and associative learning. The adaptation hypothesis explains that mirror neurons were natural selections as part of an evolution process by an organism as they helped understanding the actions of others. This means that an individual's ability to understand action and match it with executed action is genetically gained character, whereas development of this inherent character is facilitated by sensory and motor experience of observation and executions of actions.[68] On the other hand, associative learning hypothesis proposes that mirror neurons were developed as result of associative learning which suggests that each mirror neuron is forged through the sensorimotor experience of action observation and execution as part of individual's growth and development.

The connection between mirror neurons and imitation learning has been subject to study since the discovery of the mirror neuron system. Umiltà *et al*. conducted a study in which they found that the motor representation of an action performed by others can be internally generated in the observer's pre-motor cortex, even when a visual description of action is lacking. This finding also suggested that mirror neuron activation could be the basis of action recognition.[69] The interactive effect of mirror neurons and imitation learning is a crucial one in early motor development. Exposing children to a variety of imitation learning environments can have reciprocal effects on the development mirror neuron system through associative learning.

CONCLUSIONS

The function of mirror neurons is a significant factor in motor learning and development. The development of mirror neurons in the brain, leading to the ability for imitative learning is considered as one of the greatest turning points in the evolution of human beings.[70] Imitation is a major mode of learning among human beings. The role of mirror neuron in imitative learning is established beyond doubt. Many studies have shown mirror neuron activation during observation, action recognition, imagery of movements, and imitation of movements.[69,71,72] Greenough *et al*. established that the development of the nervous system depends on brain plasticity.[64] Successful engagement with complex environments, promises to have pervasive and significant effects on brain development and function. Lewis also stated that environmental restriction or deprivation early in childhood development can induce social, cognitive, affective, and motor abnormalities similar to those associated with autism.[73] Impairment of the mirror neuron system is a major cause of autism.[74] Signals from the environment and the subsequent activation of the nervous system are crucial factors for the development of the nervous system. It is proposed that this kind of activation mechanism is also crucial in the case of the development of an efficient mirror neuron system. This makes the development of the mirror neuron system and the development of movement reciprocal functions. Since mirror neurons are activated during movement recognition, observation, imagery, and imitation, it is important for children to experience complex environments from a very young age, where repeated action recognition, observation, imagery, and imitation are required. Play activities and other physical education programs provide the most stimulating environments for the repeated activation of the hMNS. Hence, exposure of children to play activities and other physical education programs is an essential factor in developing an efficient hMNS. More importantly, an efficient hMNS will reciprocally influence the development of motor ability.

RECOMMENDATIONS

There is little research done on the relationship between early play activities and sports participation in imitation learning and the development of the mirror neuron system. More research needs to be undertaken to discover how hMNS develops. Further research also needs to be undertaken to find out the exact influence of different play activities, physical education programs, and school sports programs on developing an efficient hMNS.

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