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Applications of Observational Learning in Neurorehabilitation

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Observational Learning

Observational learning (modeling, vicarious learning) is a type of learning, originated from a famous psychologist Albert Bandura at Stanford university in the 1960s, whereby the learner can acquire a new skill and behavior simply by "modeling," which simply means observing and imitating behaviors carried out by another individual (the model). This form of learning needs no reinforcement and trial and error, unlike the case of operant learning, but rather a model is required [1]. Although observational learning is still unpopular in rehabilitation medicine, it originated in the field of psychology and has been studied intensively for about half a century. In clinical psychology, observational learning has already been applied in the technique called therapeutic modeling for obsessive–compulsive disorder and specific phobias, and has been proven effective in inhibiting abnormal behaviors caused by such mental diseases. Here, we will introduce and review what psychology has revealed and studied on observational learning in order to utilize these findings for applying to rehabilitation for motor impairment after brain damage effectively.

In 1961 Albert Bandura conducted one of the best known experiments in this genre, the "Bobo doll study," to examine the effect of observational learning. In this experiment, children were assigned into three groups: one group watched aggressive acts (1), one watched nonaggressive acts (2), and one watched no acts (3). In group 1, the children watched for 10 min as adult models performed aggressive acts in the same room against a doll called "Bobo" (i.e., kicking and punching it repeatedly). In the group 2, the children observed adult models playing with toys and ignoring the Bobo doll for 10 min. Bandura examined the children's behaviors behind a one-way mirror after the adult models had left the room. It was noted that children in group 1 showed violent behaviors against the doll more frequently than children in the other groups. Interestingly, the children in group 2 showed less violent behaviors than those ingroup 3. In summary, children changed their behaviors simply by observing those performed by others, and they tended to perform more observational behaviors and fewer non observational behaviors compared with baseline (i.e., before observing the adult models).This study was the first to demonstrate that a learner can learn new behaviors simply by observing the acts of others (modeling) without any direct reinforcement.

According to Bandura's theory, known as social learning theory, the modeling process for observational learning consists of the following four stages.

- ✓ Attention: it is important for a learner to focus their attention on the model and to select one of the features to be learned in observational behavior as performed by others.
- ✓ Retention: the retention by an observer from observing a model's behavior is also important for this type of learning. In this process, visual information derived from observation is encoded to mental representation or language format to retain the information in the mind (i.e., in the brain) for a long time. This mental representation can be used for mental rehearsal, which is a process that imitates or executes the representation virtually in the mind without the presence of the model, because such training can help to consolidate the behavior in the short-term memory.
- ✓ Reproduction: this stage requires learners to reproduce the mental representation in the form of actual behavior, reducing the error of mental representation with feedback information from the physical action.
- ✓ Motivation: in this stage, intrinsic and extrinsic motivation is required to encourage the learner to perform what he/she has learned repeatedly over a long time, because to consolidate what is learned requires constant repetition.

In observational learning, the learner first has to focus on a particular feature, such as facial expression or limb movement, and also a visual component of the observed behavior that is to be learned from observation. In order to retain it, the learner then has to encode what was focused on in the previous stage to mental representation, which is the format in which it will be stored in the mind. Finally, the learner reproduces what he/she retains as mental representation for strengthening observational learning. Interestingly, according to Bandura's theory, there is a motivation process in addition to the memory process mentioned above, because the memory process requires constant repetition to consolidate what is learned from observation. Through the four stages above, modeling imparts three effects on the learner: 1) observational learning effect, 2) inhibitory and disinhibitory effect, and 3) response facilitation effect. Observational learning effect is how the learner acquires a new behavior pattern via modeling. Inhibitory and disinhibitory effects, respectively, inhibit and disinhibit a learned behavior. The response facilitation effect evokes a behavior pattern that a learner has already acquired by observing behavior performed by others. Although observational learning by modeling has been studied in social psychology, which may be somewhat removed from neuroscience and cognitive psychology, cognitive processes such as attention and retention are emphasized in social learning theory. Such characteristics of observational learning by modeling are very important when modeling and observational learning are applied in rehabilitation for motor impairment after brain damage.

Mirror Neuron System

The mirror neuron system (MNS), first reported by Giacomo Rizzolatti at Parma University, is defined as motor-related areas that are activated not only by action execution but also by action observation (AO) [2,3]. Buccino et al. showed that brain areas in the MNS have somatotopy similar to that of the classical motor cortex homunculus. In their study, brain activities were measured by functional MRI while participants carefully observed object- and non-

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object-related actions performed by another individual with different effectors (mouth, arm/hand, and foot) [4]. Observation of non-object-related actions activated frontal areas, particularly premotor areas, and the observation of object-related actions activated both premotor and parietal area processing of tactile input from effectors. During mouth actions, there is bilateral activation of Brodmann areas 6, 44, and right 45 in the ventral premotor area. During hand actions, a more dorsal part of ventral area 6 and the dorsal area of Brodmann area 44 are activated bilaterally. Finally, the observation of foot actions elicits activation of a dorsal sector of Brodmann area 6 bilaterally. These topographic patterns activated by observing different effectors are identical to those found in the primary motor cortex by Wilder Penfield [5]. This suggests that the same movement as that observed is mentally simulated in the observer's brain while watching the action performed by another individual. Observation of an action performed by others causes not only generation and running of the same motor program as that observed without overt movement but also predicts feedback information that will be retrieved when the action is executed. Oouchida et al. showed that merely observing hand movements performed by another person activated the observer's Brodmann area 2, which is a higher somatosensory area, and sensory feedback information from the hand was received from motor execution [6]. This activation in Brodmann area 2 appears to arise from the computation of estimating sensory feedback when the observed movement is actually performed. Although observation activates motor-related areas in the MNS by motor simulation, motor execution is the optimal way to activate motor-related areas. To apply observational learning to rehabilitation in the clinical situation and to execute an observing action rather than simply to observe it, reorganization of motor representation in the primary motor cortex is required.

Clinical Applications

Hemiparesis of the upper limb

Behavioral changes: Action observation treatment (AOT) is beneficial in patients who have suffered cerebral vascular accident, to improve hand motor performance. In almost all previous studies using AOT, action observation and execution training were combined in order to facilitate the effect of action observation on motor learning. For example, Ertelt et al. used action observation to improve upper extremity function in 8 patients with ischemia of the medial cerebral artery more than 6 months since onset [7]. Patients were asked to observe video clips of day-to-day hand and arm actions for 6 min; subsequently, they performed the observed action for 6 min. Each action was presented twice during the training, and 54 different video sequences were shown over the course of the study. Every day a "unit" consisting of three hand and/or arm movements of different complexity was presented. In total, each rehabilitation session lasted 90 min. Patients underwent 18 AOT sessions on 18 consecutive working days (4-week). The results showed significant improvement in motor function according to the Frenchay Arm Test (FAT), Wolf Motor Function Test, and Stroke Impact Scale after the 4-week course of treatment as compared with both stable pretreatment baseline and a control group. Improvement lasted for at least 8 weeks after the end of the intervention. This result should be treated carefully because the number of participants was only eight in this study. Similarly, Franceschini et al. showed improvement in Modified Barthel Index (BI), Fugl–Meyer (FM), Ashworth Scale (AS), FAT, and FIM by AOT in chronic stroke patients as compared with pretreatment baseline [8]. However, for patients in the subacute phase, AOT showed no change in FM, FAT, FIM, and Modified Ashworth Scale in comparison with a control group, improving scoring in only the Box and Block test [9]. In our speculation for the reason why subacute patients improved the scores in only the box and block test, according to the four stages in observational learning by Bandura's theory, the subacute patients might have a decline in focusing attention on the observing action, because of brain damage caused by stroke. These findings suggest that the timing of AOT in relation to onset must be carefully selected, and further evidence of the effects of AOT on stroke patients is required.

Change in brain activity: Previous studies reported that AOT can change brain activity in stroke patients. In a functional MRI experiment during object manipulation before and after AOT, significantly increased activity was noted in the bilateral ventral premotor, bilateral superior temporal gyrus, supplementary motor area, and contralateral supramarginal gyrus [7]. In this study, the authors concluded that action observation has a positive and additional impact on recovery of motor functions after stroke, by reactivation of motor areas. Celnik et al. investigated eight chronic stroke patients who completed a crossover randomized test [10]. In this study, although only eight patients participated, formation of motor memories measured by direction of finger movement evoked by transcranial magnetic stimulation was used as a measure of learning effect by physical therapy (PT) alone and by both PT and action observation. Two different movie clips were watched by patients: in the congruent movie, a finger was moving in the same direction as the target to be learned, and in the incongruent movie it moved in a different direction. The magnitude of motor memory formation was higher with PT+ action observation congruent than with PT alone or PT+ action observation incongruent. This effect was associated with a differential corticomotor excitability change in the agonistic and antagonistic muscles of the trained/observed movements. Congruent action observation in association with physical training can enhance the effects of motor training following stroke. This study showed that simultaneous observation of another individual performing the same action as that previously practiced could enhance the effects of motor training on motor memory formation. These effects, accompanied by specific and differential changes in brain activity, suggest the potential use of action observation as a strategy to enhance motor rehabilitation in patients with chronic stroke.

Aphasia

It is well known that in aphasic patients, word-finding difficulty is one of the most common symptoms in language breakdown and that gestures interact with speech production, enhancing word retrieval in both normal and brain-damaged subjects [11-13]. In line with this hypothesis, different rehabilitation therapies based on either the simple use of gesture [14] or gestures with verbal production [15-18] have been proposed. However, until recently, with regard to action observation, no studies have been reported on the influence exerted by gestures on lexical production. Several recent clinical studies have demonstrated the effectiveness of action observation on verb retrieval in chromic stroke patients with aphasia (see Table1).

Citing the first evidence of action observation therapy in aphasia, Marangolo et al. investigated whether observation and/or execution of semantically congruent actions would improve verb-finding difficulty in aphasic patients [19]. Their results showed a significant improvement in verb retrieval with "only congruent action observation" and "both congruent action observation and execution," which was still evident two months after the two treatments had ended. No significant effects were found in the control condition, in which patients first observed the action and then had to execute a meaningless movement. Results clearly showed that the simple observation of a semantically congruent action facilitated verb retrieval in the same way as the actual execution

Authors (Published years)	The number of subjects	Disease	Time after onset	Material of observation	Duration of treatment	Assessment of treatment	Outcome
Franceschini et al. (2012)	102 (53EG, 49CG)	Subacute stroke (hemorrhage, ischemia)	30±7 days	observe video of daily routine tasks (3min) and imitation (2 min)×3 motor sequence×2/day	4 weeks (5 sessions/ week) 20 tasks (1task/day)	FM, FAT, BBT, AS, FIM motor item	Improvement in BBT after 4weeks Improvement lasted 4 to 5 month
Franceschini et al. (2010)	28 (only EG)	Chronic stroke (ischemic, hemorrhage)	NR	observe video of hand daily actions (3 min) and imitation (2 min)×3 to 4 motor acts×2	40 min/day, 4 weeks (5 days/week)	FM, FAT, AS, FIM, BI	Improvement of BI, FIM, FM, AS, FAT Improvement lasted 2 months
Celnik et al. (2008)	8	Chronic stroke (unilateral cortical or subcortical)	more than 1 year	observe video display with the thumb movement of a healthy volunteer	30 min, 3 testing session (crossover design)	TMS-evoked movement direction	Change of TMS-evoked movement direction
Ertelt et al. (2007)	16(8EG, 8CG)	Chronic stroke (ischemic of MCA)	more than 6 months	observe video of daily life hand and arm actions (6 min), and subject performed the observed action (6 min)	90 min/day, 18 working days (4 weeks)	FAT, WMFT, SIS	The improvement FAT, WMFT and SIS The improvement lasted for 8 weeks after the end of the intervention

EG: Experimental Group, CG: Control Group, NR: Not Reported, FM: Fugl-Meyer, FAT: Frenchay Arm Test, BBT: Box And Block Test, AS: Modified Ashworth Scale, FIM: Functional Independence Measure, BI: Modified Barthel Index, WMFT: Wolf Motor Function Test, SIS: Stroke Impact Scale

Table 1: Characteristics of studies examining the effect of action observation on upper limb function of stroke patients.

Authors (Published years)	The number of subjects	Time after onset	Severity of deficit in verve retrieval	Material of observation	Experimental condition	Duration of treatment	Outcome
Bonifasi et al. (2013)	6 chronic aphasic patients	≧ 1 year	Mild to severe	128 transitive (involving the use of objects, e.g. to comb, N=103) and intransitive (not involving the use of objects, e.g. to dance, N=25) videotaped actions	1.observation of examiner 2.observation and execution 3.observation of video clips 4.observation and execution of meeningless movement	4 daily sessions for 3 consecutive days over 2 weeks	Improvement of verb retrieval was found with "observation of action","observation and execution" and "observation of action videoclips"in four patient with lexical phonologically based disturbances
Marangolo et al. (2012)	7 chronic aphasic patients	≧ 6 months	NR	115 human (N=78) and non human (N=37) videotaped actions	1.observing human actions 2.observing non human actions	5 daily sessions over 2 consecutive weeks	Improvement in verb retrieval was found only by observing videoclips of human actions which was still present 2 months after the treatment
Marangolo et al. (2010)	6 chronic aphasic patients	≧ 1 year	Mild to severe	128 transitive (N=103, e.g. to bite, to comb) and intransitive (N=25, e.g. to dance) videotaped actions	1. action observation 2. action observation and execution 3. action observation and meaningless movement	3 daily sessions of 30–45 min each for 2 consecutive weeks	Improvement of verb retrieval was found only with "action observation" and "action observation and execution" which was still present 2 months after the 2 treatments ended in 4 noufluent aphasic patients

NR: Not Reported

Table 2: Characteristics of studies examining the effect of action observation on aphasia of stroke patients.

of the action. In addition, Marangolo et al. contrasted the effects induced by observing human actions (e.g., dancing, kicking, pointing, eating) versus non-human actions (e.g., barking, printing) to further investigate the role of AOT in verb retrieval [20]. In all seven chronic patients with selective deficit in verb retrieval, significant improvement was noted through observation of video clips of human actions, but not of animal actions, such as barking. Furthermore, follow-up testing revealed long-term verb retrieval still present two months after the two treatments had ended. Bonifazi et al. recently contrasted the effects induced by observing an action (i.e., "observation of action") and observing and then executing an action (i.e., "observation and execution of action") with the results obtained by observing visually presented video clips of actions (i.e., "observation of action video clips") in two patients with semantic verb retrieval deficits and four patients with lexical phonological disturbances [21]. Results showed that in the four patients with lexical phonological disturbances, a significant improvement in verb retrieval was found for "observation of action," "observation and execution of action," and "observation of action video clips" and that the same degree of improvement was obtained through the three procedures without significant differences between them. These results clearly replicate the work by Marangolo et al. confirming that the observation of actions performed by another person is an effective approach in verb retrieval, and that the observation of action video clips exerts the same influence. As another approach for aphasia using action observation, Lee et al. proposed the IMITATE therapy: a computer-assisted system for aphasia therapy based on action observation and imitation, which consists of silent observation of audio–visually presented words and phrases spoken aloud by six different speakers, followed by a period during which the participant orally repeats the stimuli [22]. Because this system requires no therapist, the therapy is designed as a home exercise for aphasic patients.

Authors (Published years)	The number of subjects	Disease	Inclusion criteria	Material of observation	Duration of treatment	Assessment of treatment	Outcome
Pelosin et al. (2013)	38 (10EG, 10CG, 8sham 10on/off) 14 normal control(7EG, 7CG)	Parkinson's disease (Bradykinesia of finger movement)	Hoehn & Yahr=1 ～3 MMSE≧24	watch a 6 min video of repetitive finger movements consisting of the opposition of thumb to index, medium, ring, and little fingers, paced at 3 Hz	One session (6min)	Spontaneous movement rate of self-paced finger movement, Kinematic parameters describing motor performance (intertapping interval and touch duration)	Improvement of the spontaneous rate and reducing the intertapping interval to a larger extent in 45 minutes and 2 days after training.
Buccino et al. (2011)	15 (7EG, 8CG)	Parkinson's disease	Hoehn & Yahr=1.5 ～4 18-75years MMSE≧24 no depression	observe and subsequently execute, different daily actions presented through video clips	NR	UPDRS, FIM	Improvement of UPDRS, FIM
Pelosin et al. (2010)	20 (9EG, 9CG, 2 patients were excluded)	Parkinson's disease (freezing of gait)	Occurrence of freezing at least once a week (minimum score of 2 on item 3 of the FOG-Q, MMSE≧24	observe 6 video clips (each clip lasting 6 min showing strategies useful) in circumventing FOG episode (2 video clips/session)	60 min/day (observation: 24min, practice: 36min, no imitation), 4 weeks (3 sessions/week)	FOG-Q, FOG diary, TUG, 10M-WT, BBS, Tinetti Scale (part Ⅰ, Ⅱ), PDQ-39	FOG-Q was reduced in both groups. Reduction in the number of freezing of gait episodes at 4 weeks follow-up after end of training period in EG.

EG: Experimental Group, CG: Control Group, FOG: Freezing Of Gait, FOG-Q: Freezing Of Gait Questionnaire, UPDRS: Unified Parkinson's Disease Rating Scale, TUG: Timed UP And Go Test, 10M-WT: 10-Meter Walking Test, BBS: Berg Balance Scale, PDQ-39: 39-Item PD Questionnaire

Table 3: Characteristics of studies in parkinson's disease.

Taken together, two important points from the studies above should be noted: 1) simple observation of human action without its execution has the potential to reinforce verb retrieval in patients with aphasia; 2) the effects of action observation on verb retrieval persist for at least two months after treatment. These new findings represent an efficacious alternative approach to traditional rehabilitation programs for lexical deficits. However, there are few clinical studies in this field, and these include only a small number of participants. For clinical study in experimental design, a randomized control trial (RCT) is needed to provide evidence for the effectiveness of AOT in patients with aphasia.

Parkinson's Disease

In Parkinson's disease (PD), rehabilitation for motor impairment such as gait disturbance, brady kinesia, and balance disturbance is a necessary complement to pharmacological treatment. It is well known that gait disturbance, particularly short ambulatory stride length, can be improved if appropriate cues are provided [23-28]. The most effective cue is a visual one perpendicular to the direction of walking and of about one step in length [25]; in addition, auditory cues [26,28] and verbal instruction [29] are also effective to some extent. Given that visual information can improve reduced stride length in PD, observing actions performed by others may improve such motor impairments.

In a recent preliminary trial, AOT was successfully applied to rehabilitation in PD [30-32]. Pelosin et al. showed improvement in freezing of gait in patients with PD by showing video clips of strategies useful in circumventing freezing of gait [31]. In their study, such patients were asked to observe six video clips of strategies aimed at circumventing freezing of gait; for example, in the simplest version, "an actor moved their body from side to side quite slowly in the frontal plane, with both feet on the floor, standing as still as possible." After observing this movie clip, the patients were asked to practice the observed actions repetitively and accurately according to the instructions of a physical therapist. In the control group, patients were required to observe two video clips of landscape for the same duration as in the experimental group. All patients underwent PT training. By assessing freezing of gait using the Freezing of Gait Questionnaire (FOG-Q) [33], in both groups the FOG-Q score and number of freezing of gait episodes were reduced after the 4-week training period. At 4-week follow-up after the end of the training period, a significant reduction in the number of freezing of gait episodes was found only in the action observation group. This finding suggests that PT and action observation have an effect in reducing the number of freezing of gait episodes and that action observation has a longer-lasting effect for that impediment.

AOT improved autonomy in daily activities in PD patients [30]. PD patients were asked to observe, and subsequently execute, different day-to-day actions presented in the video clips (case group). Controls observed video clips with no motor content and subsequently performed the same actions as the case group. Improvement in day-to-day activity by AOT, as assessed by the Unified Parkinson's Disease Rating scale and FIM, was compared with the control group. Preliminary findings suggest that AOT may improve day-to-day activities and motor function in PD patients, thus representing a promising rehabilitative tool. However, these findings were derived from only a small number of studies on PD patients in regard to improvements in function and activity following AOT.

Cerebral Palsy

Cerebral palsy (CP) is the most common cause of disability in children. A rehabilitation approach for CP includes conventional PT, the use of those or special devices, and spasticity treatment. Despite such treatments, up to 75% of children with CP, particularly those with spastic forms, may present with motor impairment in their activities of everyday life and ambulation, and this is sometimes accompanied by cognitive and sensory deficits. Therefore, as in other areas of neurological rehabilitation (e.g., stroke or PD in adults), there is a pressing need for the introduction of a rehabilitation approach with a strong neurophysiological basis, aimed at training in the execution of meaningful tasks.

Buccino et al. investigated whether AOT has the potential to improve functional recovery in children with CP (aged 6 to 11), within a comprehensive rehabilitation program. Fifteen children participated and were randomly divided into a case group (*n*=8) and a control group (*n*=7). Six participants had left-sided hemiplegia, six right-sided hemiplegia, and three had tetraplegia; 10 were able to walk independently. Those in the case group were asked to observe video clips showing daily age-appropriate actions, and then to imitate them. Participants in the control group were asked to observe video clips with no motor content and to later execute the same actions as the case group. For 3 weeks, children in both the case and control groups attended five daily rehabilitation sessions from Monday to Friday. The primary outcome measure was the Melbourne Assessment Scale. Children were scored twice at baseline (2 weeks apart) and at the end of treatment by a physician blind to group assignment. As a result, at baseline the groups did not differ in regard to functional evaluation, but after treatment, functional score gain was significantly different between the groups. These results clearly provide experimental evidence that AOT may play an important role in the recovery of upper limb motor functions in primary school-age children with CP.

Although this study provides preliminary evidence of the efficiency of AOT in the rehabilitation of children with CP, it is worth emphasizing that the result was obtained in a small group of patients, so it cannot be considered conclusive. Larger and possibly multicenter studies are necessary to fully assess the role of AOT as a rehabilitation tool in children with CP. A further limitation of this study is the lack of a follow-up evaluation. In conclusion, AOT could be a promising and readily applied rehabilitation tool in children with CP.

Action observation can be one of the most useful methods for rehabilitation of motor impairment from children in cerebral palsy to elderly people after stroke and with Parkinson's disease compared with other learning strategies, because action observation is an automatic mental process that simulates an observing action performed by another person simply by observation. Although motor imagery has also intensively studied and been considered as a promising methods not only for a motor training in sport fields but also rehabilitation for motor impairment after brain damage, motor imagery is not always effective for those who have difficulty in voluntarily generating motor imagery, such as children and elderly patients. Recently, Gatti et al. showed the superiority of action observation to motor imagery in healthy volunteers using complex motor task [34]. Conson et al. revealed that observation of hand rotation had facilitation effects on classical motor imagery task, the hand-laterality judgment task. Although action observation and motor imagery share a common cognitive process, action observation would be more effective in motor learning than motor imagery in some tasks [35].

In clinical application of observational learning, to combine action observation with execution would be better for learning, because in social learning theory by Bandura the 'reproducing' is one of the important four stages for observational learning. And more learning effect would be acquired if noninvasive brain stimulation such as a transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS) is given to patients during action observation by enhancing brain activity. To combine with noninvasive brain stimulation is also another effective way to enhance observational learning. There are some limitations of clinical use of observational learning: for example, for those who have cannot focus on the observing action because of problem in attention and eyesight.

In conclusion, we introduced and reviewed the findings on observational learning in psychology and recent studies using action observation for observational learning in order to utilize these findings in psychology for applying more effectively to rehabilitation for motor impairment after brain damage. The observational learning has the potential to become one of the most useful and effective form of rehabilitation training from aphasia after stroke to motor impairment in Parkinson's disease, although the number of studies to date is insufficient to provide conclusive evidence of this. To apply observational learning correctly in the clinical situation, it is necessary to combine the knowledge not only from neuroscience but also from social psychology, which has investigated the effects of observational learning for several years.

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