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Review Article

Relevant factors for arm choice in reaching movement: a scoping review

Kento Hirayama, MA, RPT[1)*], Yuki Ito, RPT[2)], Toru Takahashi, PhD[1)], Rieko Osu, PhD[1)]

[1)] *Waseda University, Faculty of Human Sciences, 2-579-15 Mikajima, Tokorozawa, Saitama 359-1192, Japan*
[2)] *Waseda University, Graduate School of Human Sciences, Japan*

Abstract. [Purpose] Arm choice is an unconscious action selection performed in daily life. Even if hemiparetic stroke patients can use their paretic arm, they compensate for their movements with their non-paretic arm, leading to decreased function of their paretic arm. Therefore, we need to encourage stroke patients to actively use their paretic arm. For this purpose, it is imperative to understand the process of selection of the left or right hand by patients. Here, we conducted a scoping review to summarize the findings of previous studies on factors and brain regions related to choice of arm. [Methods] We used PubMed/Medline, EBSCO, and the Cochrane Library to obtain research literature according to the PRISMA Extension for Scoping Reviews guidelines. [Results] Twenty-five of the 81 articles obtained from the search met the defined criteria. Cost, success, and dominance were investigated as relevant factors for arm choice. We also extracted articles examining the relationship between the posterior parietal and premotor cortex activity and arm choice. [Conclusion] From these results, we considered ways to facilitate the use of the paretic arm, such as the use of virtual reality systems or exoskeletal robots to modulate the reaching cost and success rates, or non-invasive brain stimulation methods to modulate brain activity.
Key words: Action selection, Hand choice, Stroke rehabilitation

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INTRODUCTION

A hemiparetic arm after stroke is a factor that significantly reduces patients' quality of life because it impairs activities of daily living (e.g., reaching and grasping objects)[1)]. Stroke patients can recover some function of the paretic arm through rehabilitation and use it with effort[2)]. However, they gradually stop using the paretic arm and compensate with the healthy arm because the use of the paretic arm is difficult and requires intense effort. This is called "learned non-use" and is problematic because it interferes with retention and further recovery of paretic arm function[3)]. To avoid this problem, it is important to know how to facilitate the choice of the paretic arm over the non-paretic arm by understanding how the brain chooses the arm, since patients occasionally do not use the paretic arm even though they are able to use it. Hidaka et al. reported that stroke patients subsequently improved the functioning and frequency of use of the paretic arm when some frequency of paretic arm use is maintained[4)]. In contrast, Han et al. reported that a decrease in the frequency of arm use might lead to a reduction in the cortical motor areas, resulting in a loss of function in the paretic arm and a further decrease in arm use frequency[2)]. In summary, it is important to overcome learned non-use by devising a rehabilitation program to influence the patient to select the paretic arm by referring to the basic factors of arm choice.

In behavioral decision-making, target choice has been well studied and review papers of excellent quality exist[5, 6)]. However, no review has focused on effector choice. In target choice, information that contributes to the choice exists mainly in

*Corresponding author. Kento Hirayama (E-mail: kento.hirayama523@gmail.com)

the external target space. In contrast, in effector choice for the same target, the cost factors are considered to exist outside and inside the body. Hence, target and effector choices may involve different neural mechanisms. In this study, we conducted a scoping review focusing on effector choice, especially arm choice, which is particularly useful for rehabilitation. We also summarized the current known factors, neural mechanisms, and brain regions related to arm choice. This scoping review aimed to provide insights on new rehabilitation methods that could facilitate paretic arm use.

METHODS

We searched for articles using three electronic databases (PubMed/MEDLINE, EBSCO, and the Cochrane Library [CENTRAL]) based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) guidelines. The following search terms were used in the databases: ("arm choice" [Title/Abstract] OR "arm selection" [Title/Abstract] OR "hand choice" [Title/Abstract] OR "hand selection" [Title/Abstract]) AND "reaching" [Title/Abstract]). The search was conducted up to February 27, 2022.

The first and second authors selected and analyzed the articles according to the PRISMA-ScR checklist flow (Fig. 1). The eligibility criteria were original articles, written in English, which described factors related to arm choice in reaching movement. The exclusion criteria were studies involving athletes in specific sports and children aged below 18 years, review articles, books, and dissertations. We reviewed the titles and abstracts of all articles extracted using the search terms. After screening the articles, based on the eligibility and exclusion criteria, we retrieved those that possibly met the criteria. We checked their eligibility and only included articles that met the criteria. Factors determining the choice included the cost factor for easier reach, success factor for better reach, and, if these were the same, dominance and perturbation factors from other external inputs and nervous system variations. Therefore, the factors were classified into four categories (cost, success, arm dominance, and brain activity) based on the research summaries of the eligible articles. We categorized previous articles according to these four factors to evaluate how to facilitate paretic arm choice in rehabilitation. The following data were extracted from eligible articles: authors, year of publication, participants, sample size, and study description (experimental details and main results).

RESULTS AND DISCUSSION

The initial search identified 81 articles from the three databases. The 25 articles that met the eligibility and exclusion criteria were included in the analysis, excluding duplicate articles (Table 1). The 25 studies were categorized into four factor categories based on their research outlines—seven were related to cost factors (motor/cognitive costs), nine were related to success factors (including one overlapping article with other factors), seven were related to dominance factors (including two overlapping articles with other factors), and four were related to the brain activity associated with arm choice. One study did not belong to any of the factor categories.

With regard to the cost factor (motor/cognitive), four papers reported that the arm with the smaller motor cost tended to be selected[7–10]. Motor cost is generally calculated from reaching trajectory data by inverse kinematic and dynamic analyses[9, 11]. The right arm is selected more often for targets on the right side. Conversely, the left arm is selected more often for targets on the left side due to its proximity to the target and the smaller motor cost required to reach it. Schweighofer et al. performed

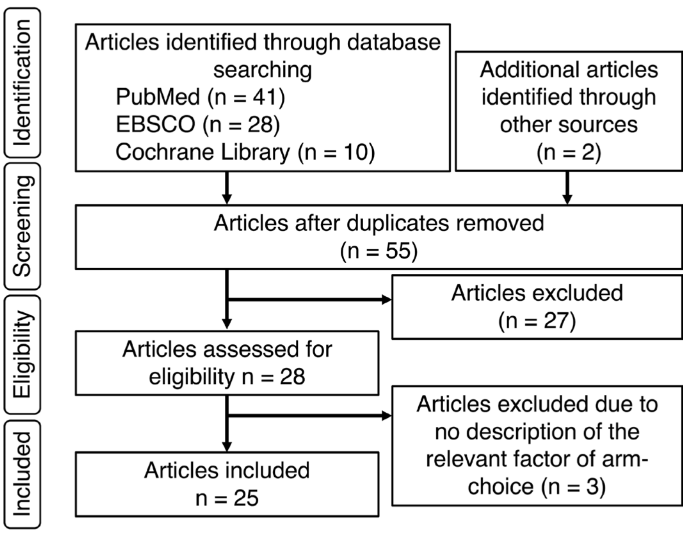

Fig. 1. Flow diagram of the searched, screened, and included articles.

Table 1. Summary of the 25 articles included in the scoping review

Author	Year	Participants	Factor	Experimental detail	Main result
McDermott & Himmelbach [7]	2019	30 healthy right-handers (27.2 ± 8.7 y)	Cost (Motor)	Using a touch-screen PC, the participants were asked to select an arm to reach a single target presented at low, medium, and high target heights. A weight was attached to the non-dominant arm. The choice rate of each arm was measured.	The choice rate of the non-dominant arm significantly decreased in the weighted condition compared to the unweighted one. However, the choice rate of the dominant arm was more than that of the non-dominant arm in the condition when the target was in a higher position.
Schütz & Schack [8]	2020	54 healthy (23.6 ± 3.2 y), 27 right and 19 left-handers	Cost (Motor)	Participants performed a task of catching a ball rolling from behind a partition cloth on nine rails with either their left or right arms. The choice rate of each arm for each rail was measured.	The right arm had a higher choice rate for the right rail and the left arm for the left rail. The center rail had a high choice rate of the dominant arm.
Schweighofer et al.[9]	2015	26 healthy right-handers (23.5 ± 1.41 y)	Cost (Motor), Success	Participants chose either the left or right arm to reach a target presented at twelve target positions around a circumference centered on the starting position. The rates of arm choice and reaching success were measured, and the cost of reaching was calculated.	The right arm was chosen more often for upper-right and lower-left targets on the horizontal plane, and the left arm was chosen more often for upper-left and lower-right targets. Reaching success rates were higher for the dominant arm. Mathematical modeling suggested that the reaching success rate and cost affected the arm choice.
Habagishi et al.[10]	2014	16 healthy (21–34 y), 13 right-handers, 3 left-handers	Cost (Motor)	A robotic arm was used to perform a reaching task with the arm choice under velocity-dependent resistance on the dominant arm. The target position was a point on the body centerline. The choice rate of each arm was measured.	The choice rate of the dominant arm decreased. The results suggest that motor cost is related to arm choice.
Bakker et al.[12]	2018	19 healthy right-handers (19–40 y)	Cost (Motor)	Participants performed an arm-selective reaching task with head and gaze directions fixed at −18, −9, 0, 9, and 18 degrees to the left and right (0 degrees being the body center). Eleven target positions were set symmetrically in a semicircle from −60 to 60 degrees. The choice rate for each arm was measured.	The choice rate of the arm contralateral to the head and gaze direction increased.
Bakker et al.[13]	2019	12 healthy right-handers (20–32 y)	Cost (Motor)	The effect of lateral acceleration of the body on arm choice were examined. Eleven target positions were set symmetrically in a semicircle from −60 to 60 degrees. The choice rate for each arm was measured.	The choice rate of the arm contralateral to the direction of the acceleration increased.
Liang et al.[14]	2018	11 healthy right-handers (mean 24 y)	Cost (Cognitive)	Participants performed an arm choice task, reaching a specified target in multiple targets. Three levels of cognitive load were set up by changing the number of targets. Finally, the arm choice rate was measured.	Increasing cognitive load increased the variability of arm choice tendencies and the choice rate of the dominant arm.
Stoloff et al.[15]	2011	83 healthy right-handers (18–30 y)	Success	The success rate of the dominant arm was decreased, and that of the non-dominant arm was increased without the participant being aware of it during an arm choice reaching task with seven target positions. The arm choice rate was measured.	The choice rate of the dominant arm decreased, and the choice rate of the non-dominant arm increased.

Table 1. Continued

Author	Year	Participants	Factor	Experimental detail	Main result
Coelho et al.[16]	2013	10 healthy right-handers (20.5 ± 1.4 y)	Success	Participants performed an arm choice reaching task with eight target positions. The arm choice rate was measured. In addition, the reach trajectories and the inter-joint motor control were examined by inverse dynamic analysis.	The ipsilateral arm was selected more often for left-right spatial targets, and the dominant arm had a higher arm choice rate for body-centered targets. In addition, the dominant arm had a more linear reach trajectory, smaller error at the endpoint, and better control between joints, than the non-dominant arm.
Przybyla et al.[17]	2013	48 healthy right-handers (18–34 y)	Success	Participants performed an arm choice reaching task with 32 symmetrical target positions. Conditions with and without visual feedback were set up. The arm choice rate and the accuracy of the reach were examined.	In the condition with visual feedback, the right arm had a higher reach accuracy and choice rate than the left arm, and vice versa in the condition with no visual feedback.
Stins et al.[18]	2001	7 right-handers and 7 left-handers	Success	Participants performed an arm choice task to reach and grasp cups in seven symmetrical positions. Conditions with full (water) or empty cups were set up. The arm choice rate and kinematic reaching data were measured.	The arm ipsilateral to the target was more likely to be selected. Furthermore, the position at which the arm choice tendency switched was strongly correlated with the position at which the reaching speed decreased; this tendency was more robust in the full cup condition than in the empty cup condition.
Salters et al.[19]	2021	50 healthy (20.1 ± 1.78 y, 45 right-handers)	Success	Participants performed, with either their left or right arms, (1) grasping a cup, (with or without water) placed in five symmetrical random positions, and pouring the cup's water into another cup placed in the center (in the no-water condition, imitating the action), (2) grasping the white part of a stick placed at a random position among three symmetrical locations (the stick was colored black and white with the center of the stick as the border), (3) grasping a hammer (the direction of the hammer's handle was set for each of four conditions: up, down, left, and right). In each task, the choice rate of each arm was measured.	In the first task (1), the choice rate of the arm near the cup was high. In the second and third tasks (2 and 3), the direction of the grasping part affected arm choice for sticks and hammers placed in the non-dominant arm space. In contrast, the dominant arm was selected more often, regardless of the direction of the grasping part, when the target was placed on the side of the dominant arm.
Salters & Scharoun[20]	2022	33 right-handers (20.1 ± 1.78 y)	Success	Participants performed an arm choice task in which they grasped a cup at five positions. In a unimanual condition, they only grasped the cup. In a bimanual condition, they grasped the cup and poured water into it with their other arm, from a pitcher placed in the center. The choice rate of each arm was measured.	In the unimanual condition, the arm near the cup was chosen more frequently, while in the bimanual condition, the arm that was further from the cup was chosen more frequently.

Table 1. Continued

Author	Year	Participants	Factor	Experimental detail	Main result
Scharoun et al.[21]	2016	39 right-handers (18–30 y)	Success and dominance	Participants performed the following four arm choice tasks with either their left or right arms: (1) pickup task: participants picked up a cup from three positions (the direction of the handle was random). (2) pour task: participants picked up a cup from three positions and poured water into the cup from a pitcher in front of them with the other arm. (3) pass task: participants took a cup and passed it to the person sitting in front of them. (4) pour and pass task: the participants took a cup, poured water into it from the pitcher with the other arm, and passed it to the person sitting in front of them. In all the tasks, participants did not need to grasp the handle. The arm choice rate was measured.	The choice rate of the arm closer to the cup was higher. In the unimanual task (pickup and pass task), the dominant arm choice rate was higher than that in the bimanual task (pour task). In the pour task, there was no significant effect of handle orientation when the cup was placed on the non-dominant arm side, while the handle orientation affected arm choice when the cup was placed in the center or the dominant arm side. In the pass condition, the frequency of grasping the handle decreased compared to the other conditions. The results suggest that post-reaching action and partner presence affect arm choice.
Bryden & Huszczynski [22]	2011	45 right-handers (mean age 20.6 y)	Success and dominance	Participants performed an arm choice task of grabbing a cup placed in three positions (left, middle, right) and passing it to the opposite hand. The handles were oriented in three directions: left, neutral, and right. The arm choice rate was measured.	The arm on the same side as the cup position and the handle direction was likely to be selected. The dominant hand was more likely to be selected for the cup near the center.
Kim et al.[24]	2011	11 healthy right-handers (19–23 y)	Dominance	Participants performed an arm choice reaching task with nine target positions. The arm choice rate and the joint movement were measured using a motion tracking system.	The arm closer to the target was chosen more often. The dominant arm was chosen more often for targets near the center. For edge targets, the amount of joint movement was relevant to arm choice.
Gabbard et al.[25]	1997	144 healthy (mean 20.9 y), 84 right and 60 left-handers	Dominance	Left and right-handed participants performed an arm choice task with four target positions, and the arm choice rate was measured.	Left-handers used the non-dominant arm for the contralateral target more often than the right-handers did. This result suggested that left-handers were less consistent in their arm choice preferences than right-handers.
Liang et al.[26]	2019	12 healthy (mean age 23 y), ten right and ten left-handers	Dominance	Participants performed an arm choice task that asked them to reach the same mark as the one presented immediately before from among 16 different marks. Three levels of perceived cognitive load were set. Finally, the arm choice rate was measured.	In the low cognitive load condition, the choice rate of the arm closer to the target was higher. In contrast, the choice rate of the arm farther from the target increased in the high cognitive load condition. In particular, left-handers selected the arm further from the target more often than the right-handers did.
Mani et al.[27]	2014	14 right-handers with stroke (seven each with left and right hemisphere damage)	Dominance	Right-handed patients with right-hemisphere and left-hemisphere injuries (paralysis severity controlled) were asked to select an arm to reach a target presented at 32 symmetrical target positions. The arm choice rate for each target was measured.	Patients with left hemisphere injury (right arm paralysis) were more likely to use the paretic arm than those with right hemisphere injury (left arm paralysis). This result suggested that the dominant arm influenced the use rate of the paretic arm in stroke patients.
Kim et al.[28]	2022	22 right-handers with stroke (twelve right paralyses and ten left paralyses)	Dominance	Patients performed an arm choice reaching task with 35 target positions within a limited time. Failure to reach the target within the time limit was a failure trial, and the success rate of each arm was measured. In addition, the motor cost was calculated from the trajectory data, and the arm choice rate was measured.	Right hemiparetic patients continued to use the paretic arm after a failed reach with the paretic arm. In contrast, left hemiparetic patients showed increased non-paretic arm choice after a failed reach with the paretic arm. Arm choice in stroke patients is related to the dominant arm.

Table 1. Continued

Author	Year	Participants	Factor	Experimental detail	Main result
Hamel–Thibault et al.[31]	2016	19 healthy right-handers (mean age 25, 21–34 y)	Brain activity	Participants performed an arm choice reaching task with nine target positions. EEG measurements were done during the task, and the relationship between arm choice and EEG features was examined.	The delta band intertrial coherence of the contralateral premotor cortex at the target presentation correlated significantly with the arm choice rate.
Oliveira et al.[32]	2010	13 healthy right-handers (mean age 19.8, 18–21 y)	Brain activity	Participants performed an arm choice reaching task with nine target positions. A single pulse of transcranial magnetic stimulation (TMS) was applied to the left or right posterior parietal cortex (PPC) 100 ms after the target presentation. The arm choice rate was measured.	With the left TMS condition, the choice rate of the right arm decreased, and that of the left arm increased. In contrast, no significant changes were observed with the right TMS condition.
Hirayama et al.[33]	2021	16 healthy right-handers (21.3 ± 1.3 y)	Brain activity	Participants performed an arm choice reaching task with nine target positions. During the task, transcranial direct current electrical stimulation (tDCS) was applied for 10 minutes to enhance or inhibit left and right PPC activity. The arm choice rate was examined.	In the condition with inhibition of the left PPC and facilitation of the right PPC, the right-arm choice rate decreased, and the left-arm choice rate increased, compared to the pre-stimulus condition. In contrast, no significant changes were observed in the left and right tDCS switched conditions.
Fitzpatrick et al.[34]	2019	23 healthy right-handers (23.2 ± 3.9 y)	Brain activity	In a functional magnetic resonance imaging system, participants performed an arm choice reaching task with 16 target positions. The arm choice rate and brain activity were measured.	Left-arm choice correlated with activity in the right PPC, and right-arm choice correlated with activity in the left PPC and left dorsal premotor cortex.
Tani et al.[42]	2017	11 healthy right-handers (27 ± 1.8 y)	None	Participants performed an arm choice reaching task with eleven target positions. Auditory stimuli were applied to the right or left ear 100 ms after the target presentation. The arm choice rate was measured.	Right auditory stimulation significantly increased right-arm choice compared to the no-sound and left-sound stimulation conditions.

the reaching task by selecting either the left or right arm to reach a target presented at one of 12 target positions on a circle centered on the starting position of the reach[9)]. They estimated the motor cost of reaching for each of the left and right arms by performing an inverse kinematic analysis on the reach trajectory data. The right arm had a smaller motor cost to reach into the distal right and proximal left spaces, while the left arm had a smaller motor cost to reach into the distal left and proximal right spaces than that of the other arm on the horizontal plane. The results suggested that the arm choice tended to be in accordance with this motor cost characteristic. Habagishi et al. applied velocity-dependent resistance to the dominant arm using a robotic arm in a reaching task that involved arm choice. The choice rate of the dominant arm was significantly decreased compared to that of the other arm[10)]. Even in simple single-arm reaching movements, it has been shown that movement is controlled to minimize the motor cost[11)]. It is possible that arm choice is also determined to minimize motor cost. Bakker et al. examined the effects of fixing the participant's head or gaze direction in various positions on arm choice on the left and right sides[12)]. Consequently, they reported an increase in the frequency of choice of the contralateral arm to the head or gaze direction. They described that the change in the gaze and head direction possibly led to misperception of visual information, such as the target position, and miscalculation of movement preparation, such as the reaching trajectory and cost. In addition, Bakker et al. examined the effects of acceleration in the left-right direction on arm choice by sliding the participant's chair sideways during an arm choice task[13)]. They observed an increase in the probability of arm choice contralateral to the direction of acceleration. They discussed the effect of the acceleration of the body on the calculation of the reaching trajectory and cost. Moreover, Liang et al. reported that cognitive costs affected arm choice[14)]. They presented multiple marks on a display and set a task in which participants were asked to reach the same mark as the immediately pre-presented mark with a choice of either the left or right arm. In that visual search task, they set three levels of difficulty and examined the effect of cognitive cost on arm choice. They reported that the greater the cognitive cost, the more ambiguous the arm choice tendency became. We thought that the larger cognitive costs associated with visual information processing possibly made the optimal arm choice more difficult.

With regard to the success factor, successfully reaching a target is a reward for behavior and reinforces the choice of that arm. Reportedly, the arm with the higher reaching success rate is more likely to be chosen[9, 15)]. Stoloff et al. used a virtual environment to decrease the reaching success rate in the dominant arm and increase that in the non-dominant arm, unnoticed by the participants[15)]. They reported a decrease in the choice rate of the dominant arm and an increase in the choice rate of the non-dominant arm. In addition, they observed that reaching accuracy was related to reaching success. Generally, reaching accuracy is defined as the error at the end position, the trajectory's linearity, and tinter-joint coordination during the reach. Reportedly, the arm with the more accurate reach is chosen[16–18)]. These authors reported that the dominant arm had a higher choice rate than the non-dominant arm, which was related to a smaller error at the endpoint and a linear reach trajectory. Furthermore, some studies used a task that combined reaching and grasping and/or pouring water into a cup[19–22)]. The studies of the grasping and pouring movements suggest that factors such as cup handle orientation are related to arm choice, independent of the cost of the reach. These studies suggest that the success factor is related to the choice of arm. As a mechanism for behavioral choice, it has been shown that behavior is selected to maximize the summed reward[23)]. This model suggests that behavior choice learning proceeds through a process in which, after performing a certain behavior, positive feedback reinforces the choice of that behavior, and negative feedback inhibits the choice of that behavior.

With regard to dominance factors, a high rate of dominant arm choice has been reported for targets around the left and right centers[24)]. In addition, left-handed individuals reported a higher probability of selecting an arm for a target farther from the target than the other arm and showed a less consistent arm choice than right-handed individuals[25, 26)]. Furthermore, two studies conducted tasks in which stroke patients were asked to select either the paretic or non-paretic arm to reach the target[27, 28)]. These studies reported that patients with dominant arm paralysis had less reduction of paretic arm use than patients with non-dominant arm paralysis of similar severity. These studies suggest that the habitual factor in selecting the dominant arm is related to arm choice. Reportedly, there are two mechanisms of action choice: a goal-directed process, in which choice is made by calculating the determinants for optimal choice in a given environment, and a dominant process, in which dominant behavior is selected independent of the environment[29)]. In the case of arm choice, we consider that the goal-directed process, which is related to cost and success rate factors, and the dominant process, which is associated with the dominant arm, are related to arm choice. In particular, the dominant process has a large influence on arm choice process and possibly increases the probability of dominant arm choice when time limits prevent the calculations of the goal-directed process or when the cost is in equilibrium around the left-right center of the target[30)].

With regard to the brain activity associated with arm choice, some studies reported that activity in the pre-motor and posterior parietal cortexes are associated with arm choice[31–34)]. Hamel–Thibault et al. reported a significant correlation between the delta band intertrial coherence of the contralateral premotor cortex at the target presentation and the arm choice rate[31)]. Fitzpatrick et al. reported increased activity in the contralateral posterior parietal cortex for left-arm choice and the contralateral posterior parietal and dorsal premotor cortex for right-arm choice after target presentation, compared to the condition that predetermined the reaching arm without arm choice[34)]. Oliveira et al. used single-pulse transcranial magnetic stimulation to provide a noise stimulus to the left or right posterior parietal cortex 100 ms after target presentation during the arm choice task[32)]. They reported that stimulation of the left posterior parietal cortex decreased the probability of right-arm choice and increased that of left-arm choice. Moreover, Hirayama et al. used transcranial direct current stimulation to simultaneously perform anodal or cathodal stimulation on the left and right posterior parietal cortexes[33)]. Right-arm choice decreased and left-arm choice increased significantly in the conditions in which cathodal stimulation and anodal stimulation were performed on the left and right posterior parietal cortexes, respectively, compared to the arm choice rate of the pre-stimulation condition. These results suggest that the premotor and posterior parietal cortexes are possibly involved in arm choice. The calculation of desired trajectories, necessary for estimating motor costs, is thought to be related to the posterior parietal cortex[35, 36]. Moreover, the posterior parietal cortex has been reported to integrate various sensory data, such as somatosensory and visual information, and send out important information for motor planning[37, 38]. These findings suggest that the posterior parietal cortex has an important role in selecting the optimal arm by calculating multiple sensory inputs. Furthermore, the premotor cortex is a higher-order motor-related area responsible for motor planning[39, 40]. Thus, we consider that arm choice is decided by a process in which the various factors related to arm choice are integrated in the premotor cortex, and the motor plans for the left and right arm are generated based on this information. Furthermore, neural activity related to action selection has been observed in the premotor cortex in studies of action selection, in which multiple targets are selected by reaching with a single arm[5, 41]. This suggests that the premotor cortex could be particularly important for arm choice as it integrates information on relevant factors.

Finally, one study did not belong to any of the factor categories. Tani et al. provided auditory stimulation to either the left or right ear of the participants 100 ms after the target was presented during a reaching task with arm choice[42]. In the condition with auditory stimulation to the right ear, the rate of choice of the right arm was significantly increased compared to the no sound condition, suggesting that auditory stimulation affects arm choice. Although the mechanism by which auditory stimuli affects arm choice is unknown, this result suggests that various sensory information inputs are related to arm choice.

This study has some limitations. First, this was not a systematic review, and no quality rating of included articles was conducted. Second, we only included publications written in English, potentially leading to missing evidence from other languages.

In conclusion, factors related to arm choice were classified into cost (motor and cognitive), success, and dominance factors. Furthermore, the posterior parietal and premotor cortexes were reported as brain regions related to arm choice. In future studies, we plan to propose interventions to facilitate the use of the paretic arm in stroke patients based on the results of this review. As specific interventions, the use of the paretic arm could be promoted using an exoskeletal robot or a virtual reality system[43, 44] to decrease the motor cost or increase the success rate of the paretic arm. Moreover, changing the activity of the posterior parietal and premotor cortexes of stroke patients by using non-invasive brain stimulation techniques, such as tDCS and tACS, may effectively increase the use of the paretic arm[45].

Preprint publication

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Conflicts of interest

The authors declare no conflicting interests.

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