A massively successful experience is needed for spontaneous use in post-stroke: a randomized controlled trial

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Abstract

Background: Motivation to use the more-affected arm is an essential indicator of recovery in stroke survivors. This study aimed to investigate whether personal mastery experience via intensive repetitive reaching movements with autonomy support may increase self-efficacy and thus increase performance and use of the more-affected arm in mild-to-moderate subacute to chronic stroke patients.

Methods: Twenty-six participants with stroke were divided into two groups: a motivation group (with autonomy support) and a control group (without autonomy support). Five weeks of training and test sessions were administered using the individualized motivation enhancement system that we developed. The task difficulty parameter modulated the time limit for attaining targets to provide autonomy support. We analyzed various clinical and behavioral measures using mixed-effect models.

Results: Successful experiences did not change in the control group ($p = .129$),but dramatically increased in the motivation group ($p < .0001$). Performance significantly improved in the retention test for both groups ($p < .0001$), without any group differences ($p = .329$). However, the motivation group exhibited a dramatic increase in the use of the more-affected arm ($p < .0001$), whereas the control group did not (p

Conclusions: The successful experience of personal mastery accomplished by autonomy support increased the use of the affected arm. Autonomy support in the motivation group may make a participant aware of the training goal: to use the more-affected arm as much as possible or make the affected arm use more habitual.

Trial registration: The study was registered with The Clinical Research Information Service (CRIS), KCT0008117. Registered retrospectively on January 13, 2023, at https://cris.nih.go.kr/cris/search/detailSearch.do/23875

Introduction

The functional improvements obtained through rehabilitation often do not lead to an increase in the use of the more-affected arm in real-world situations [1,2]. Various clinical trials, such as constraint-induced movement therapy (CIMT)[3,4], task-oriented movement therapy [5,6], and high-dose training [7,8] have been conducted to overcome this discrepancy in the function and use of the upper extremity (UE) by increasing the use of the more-affected arm.

Recently, motivational factors, such as autonomy support and self-efficacy have been researched to overcome this discrepancy and enhance the recovery in post stroke [9–12]. *Autonomy support* is the principal concept of a patient-centered intervention program, in which patients actively participate in the planning and selection of the order and difficulty of tasks [5]. *Self-efficacy (SE)* represents one's belief in her/his capacity to complete a certain task [13,14], and its most powerful source is the personal mastery experience of performing a task successfully. Autonomy support and self-efficacy have been used in stroke rehabilitation. For example, Winstein et al. proposed the Accelerated Skill Acquisition Program (ASAP) for upper-extremity stroke rehabilitation [5]. When comparing dose-equivalent usual occupational therapy, ASAP provides enhancements in various patient-reported outcome measures, such as motor activity log-28 in patients with acute to subacute stroke. The high dose of ASAP also showed better recovery than the low or medium dose of ASAP in patients with chronic stroke [8]. However, few studies have attempted to connect autonomy support and self-efficacy, although they are key for successful intervention in addition to patients' motivation and devotion to the program [15,16].

In line with previous studies, we hypothesized that mastery experience with task success accomplished through autonomy support (e.g., active participation in selecting task schedules) may enhance self-efficacy. Consequently, we expected increased self-efficacy to facilitate the use of the more-affected arm, as suggested by other researchers [4,9,10,17]. While previous studies employed task-oriented practices that require skilled/sophisticated movements, we provided rather simple high-dose repetitive reaching movements that promise stroke patients a greater chance of obtaining personal mastery experience. Since usual therapy sessions typically have 80-100 repetitions of UE movements [18], the number of repetitions per session in previous studies might have been insufficient. The increased repetition achieved with task success and autonomy support in our study would be beneficial for learning how to use the more-affected arm. Concurrently, to maximize the learning effect on using the more-affected arm spontaneously, a "choice training," which allowed participants with stroke to choose their arms to use, was applied.

Our other objective was to investigate this hypothesis using a novel IT device that allows patients to modulate their task difficulty for autonomy support. A previous study with UE training via IT systems showed that successful experience in reaching increased the use of the left non-dominant arm in healthy participants [19], and the visual augmentation providing more successful experience improved the use of the more-affected arm in stroke survivors [20]. However, few IT systems allow the active involvement of participants in changing

task difficulty or training schedules during training. Consequently, it was difficult for the former systems to capture patients' behaviors during the training sessions that included selection of the task difficulty and changes in motivation variables (i.e., self-efficacy and outcome expectation) and to hinder the investigation of dynamic changes during the training. Our novel system overcomes these limitations.

This study aimed to investigate whether the successful experience of personal mastery via high repetitive reaching movements with autonomy support may increase self-efficacy, and thus may increase the function and use of the more-affected arm in mild-to-moderate subacute to chronic stroke survivors. Dynamic changes in self-efficacy and autonomy support, represented by task difficulty during training, were also studied.

Methods

Participants

Twenty-six patients with subacute to chronic stroke were included (Figure 1). They were allocated to two groups: motivation and control groups. Table 1 presents the general characteristics of the participants. All participants were right-handed, had mild-to-moderate impairment in the upper extremity, and had the motor capability to complete the task using their more-affected arm. The inclusion criteria were as follows: (1) patients with first ever ischemic and hemorrhagic stroke in the either subacute or chronic stage (at least one month after stroke onset), (2) individuals with movement difficulties in the upper limb (Fugl-Meyer Assessment score >=19)[8,21], (3) individuals without communication or intellectual problems (Mini-Mental State Examination, score >= 24), (4) right-handedness (Edinburgh handedness score >=70%), and (5) ability to reach all targets displayed on the touch screen used in the experiment. The exclusion criteria were: (1) Individuals with multiple stroke attacks or who had undergone orthopedic surgery on the upper extremity, and (2) visuomotor neglect as measured by Albert's test [22]. Participants were randomized into the motivation and control groups, and those in the motivation group completed a training schedule to learn the use of the more-affected arm, while the control group did not. This study was approved by the Institute of Research Board of the Jeonju University(jjIRB–190414–HR–2019-0409). All participants read and signed a written consent form before starting the experiment.

Individualized Motivational Enhancement System (IMES)

We developed a new training system, called the individualized motivation enhancement system (IMES), which changes task difficulty by varying the time limit for reaching movements. IMES comprised a 55" touchscreen, used to provide targets and collect data; a main computer, used to control the overall programs; and a height controllable desk used to adjust the screen to the height of individual participant (Figure 2A). Our system provides game-based test and individualized training sessions requiring participants to catch targets on a 2D touch screen by moving their more or less affected arms (see **IMES: test and individualized training sessions** below for details). In general, at the beginning of the sessions, the participants were asked to place their index fingers at the home position, which was set 20 cm apart from the xiphoid process of the subject's trunk. Then, the target appeared in one of the hundred predefined locations (17 angles between 10 to 170 with 20 degrees of the interval, the six different distances between 10- 30 cm with the interval of 5cm)(Figure 2B). The maximum distance of the targets was 50 cm apart from the subject. The participants with stroke were instructed to "catch the target as fast as possible before the targets disappear and then return to the home position." Each target appeared and disappeared within a predefined time limit. A movement was counted as successful only when the participants succeeded in catching the appeared target within the set time limit. The time limit was altered to control the task difficulty. If the participants succeeded in catching the targets, they earned game scores, which appeared in the top-left corner of the screen for the motivational purpose. The total number of targets and time limits varied across test and training sessions, as explained in the following sections.

IMES: Test session

During the IMES test session, the impairment, performance, and use of the more-affected arm were measured (Figure 2C). 45 targets of out 100 targets were used in the test session (Figure 2B). There were two different conditions: no-time constraint and fast-time constraint. The No-time constraint condition had no time limit; the fast-time constraint condition had an approximately 500 ms time limit for the target reaching. The time limit in the fast-time constraint condition was based on the previous study investigating different movement duration for the targets in different locations [23,24]. Each condition had two blocks: free- and forced-choice blocks. During the free-choice block, the participants freely selected the arm they used. During the forced-choice block, the participants were asked to use only the less-affected (LA) arm and then to use the more-affected (MA) arm to reach all targets. The total number of targets that the participants successfully reached in the free- and forced-choice blocks in the fast-time constraint condition represented the more-affected

arm performance and use, respectively [24,25]. Since the participants were informed that there was no correct or wrong answer for free-choice blocks, the spontaneous arm choice pattern (i.e., the use of the more-affected arm) was successfully measured. We also included the forced-choice block in the no-time constraint condition to measure the movement duration for each arm and used each movement duration to designate the time limit for the training session.

IMES: Individualized training session

The IMES training session was designed to provide a customized training protocol based on the individual's functional ability. To achieve this goal, we modulated the time limit. As previously mentioned, the movement duration for each target was measured for each arm during the forced-choice block of the no-time constraint condition in the IMES test session. Movement time was defined as the default time limit with a zero-***task difficulty parameter (TDP)***. TDP was a parameter to modulate the task difficulty by changing time limit for each target so the tester or the participant manipulated the TDP between -50% and +50% with 10% of interval [+- 50, 40, 30,20,10, 0]. If the TDP was set at +10%, the time limit became 10 % longer than the actual movement time of the more affected arm. If the TDP was negative, the time limit was shortened. The time limit differed depending on which arm the participants used. Most patients with stroke showed slow movement times when using their more-affected arm, thus durations of the more- and less-affected arms were measured separately, and these valued were applied during the training. For example, for the target on the left corner, the time limit was 580 ms for the more-affected arm, but 350 ms for the less-affected arm.

The participants were asked to successfully use the more-affected arm to catch the targets as many times as possible using either the more- or less-affected arms during the training sessions. If they missed several targets at the beginning, the tester recommended speeding up or switching arm. In general, the participants completed five training blocks, each consisting of a total of 100 targets, per day unless they felt tired or experienced pain.

Intervention for learning use of the more-affected arm with and without autonomy support

To investigate the effects of autonomy support on the outcome measures (or participants' behaviors), we randomized the participants into two groups: motivation and control. Participants in the motivation group were able to adjust their task difficulty actively, although they did not exactly recognize how the IMES modulated it. After each training block, the participants were asked whether they wanted to make the task more difficult or not. The time limit became faster or slower in accordance with the participants' choice for TDP In contrast, the participants in the control group did not have any opportunity to adjust to task difficulties. Instead, it was randomly selected between -20 and +20 for each training block. On the first training day (Day 2), we intentionally set TDP to be more positive than on the other days, as we thought that this would be helpful to prevent the negative failure of using the more-affected arm at the beginning of the training.

We administered the social comparative verbal feedback to only the motivation group. This consisted of phrases such as "the active participant, like you, normally performs well at this type of game." However, the participants in the control group received only brief plain verbal feedback, such as "good job".

Experimental protocol

The overall experiment was conducted for five weeks with 11 visits (Figure 2D). Screening examinations were performed at least one week before the experiment. On the first day, the participants who met the inclusion criteria were randomly allocated into two groups. All participants completed the baseline test on Day 1 in the first week, and subsequently underwent IMES test session and clinical assessments. The patients performed the five blocks of the training session during the second to fourth weeks (Days 2-10), each lasting about an hour. The training session was performed three times a week for three weeks. Subjects were asked about the self-efficacy and outcome expectation immediately after each training block. In the last fifth week, a retention test, identical to the baseline test, was conducted (Day 11).

Outcome measurements

The primary outcome was impairment, performance, and use of the more-affected arm measured by both IMES system and clinical tests and the secondary outcome was Participant's behavior of autonomy support and motivation to use the more-affected arm.

IMES system: measuring impairment(movement duration), performance(forced-choice), use(free-choice) of the more-affected arm in the fast-time constraint condition

The IMES test sessions (baseline and retention tests) measured impairment, performance, and use. Impairment was assessed by the average movement duration of the more-affected arm in seconds (log-transformed) during the forced-choice block of the no-time constrained condition. Performance and use were measured by the total number of successful reaching with the more-affected arm during the forced-choice block and free-choice block of the fast time-constrained condition, respectively (see IMES: test session for more details).

Clinical test: Measuring impairment, performance, use of the more-affected arm

Clinical tests were used to evaluate the changes before and after IMES training at baseline and retention tests. The Fugl-Meyer Assessment for Upper Extremity (FMA) was used to measure impairment. The Wolf motor function test with time domain (WMFT-time) and the actual amount of use with the quality of movement scale (AAUT-QOM) were used to evaluate the performance and amount of use of the more-affected arm, respectively.

We used only 8 of the 17 items in WMFT, which were relevant to reaching movement, and 14 of 17 items in the AAUT, included purposeful UE movements. The sum of each item on the FM and the average time of 8 WMFT items were calculated. The AAUT was scored based on the quality of movement (AAUT-QOM). These clinical tests are standard in stroke rehabilitation, and their validity and reliability have been proven in prior studies.

Participant's behavior of autonomy support

We focused on two important sub-phases of the training sessions: early (the first two training days) and late (the last two training days) phases to study the changes in TDP, successful/failed experience, and success rate during the training. The average values of these variables were used to compare phase differences.

The TDP, which either the tester or the participant selected, was recorded in each IMES training block across the entire training session. The total number of successful experiences and failures in each IMES training block were counted when the participant used the more-affected arm successfully or unsuccessfully. Success rate was defined as the number of successful uses of the more-affected arm over the total use (success + failure) of the more-affected arm and represented as a percentage.

Measuring motivation to use the more-affected arm

Confidence in the Arm and Hand Movement (CAHM) was used to measure the participant's motivation to use the more-affected arm[11]. The original CAHM was modified to fit the IMES, and the participants' expectations and confidence while performing the task were measured. SE was the question, "How confident are you when catching an animal character using the more-affected arm?". OE was the question, "If you take animal characters using the more-affected arm in the next block, how many characters can you catch?". We used a scoring board, with the scores for both questions ranging from 0 to 100. Because SE and OE were measured only during the training sessions, the data were obtained from the first and last training days (Days 2 and 10). There were five SE and OE scores per training day, for which the scores were averaged for further analysis.

Blinding

An independent evaluator blinded to participant recruitment, data collection, and group allocation analyzed all outcomes. The participants did not know which group they were in, and they were not allowed to discuss their interventions with each other.

Statistical analysis

All statistical analyses were performed using the R Studio 1.2. and the significance level was set at $p<0.05$. Mixed-effect linear regression analysis was used to determine the impact of an individualized training program of IMES and clinical and motivational variables. The Test (baseline vs. retention) and group (motivation vs. control) were set as categorical variables of the fixed effect, and each individual was set as a random intercept.**F**our different analysis models were constructed, as follows: The first two models included one factor only (e.g., Group or Test), and the last two models had two factors with and without interaction terms (e.g., Group + Test for model 3, Group * Test for model 4). The *anova* function() in R studio was applied for the model comparison and to define the best-fit model with the lowest Akaike information criterion (AIC). Once the best-fit model was selected, the model diagnostics, including visual inspection of outliers via the *qq-norm* plot, calculated Cohen's distance. The effect size, measured as omega-squared (w^2), was calculated for further information.We used Phase (early vs. late) instead of Test (baseline vs. maintenance) when analyzing participants' autonomy-supporting behavior. To investigate whether changes in successful experience during training sessions were associated with changes in the IMES

and clinical and motivational variables, correlation analyses were conducted using Spearman or Pearson methods depending on the data distribution.

Results

Participants

Twenty-six individuals with mild-to-moderate motor impairment in subacute or chronic stroke participated in this study (Tables 1). The motivation and control groups did not differ in age, FMA, MMSE, and Edinburgh tests (all, p >.05). All participants were at least six months after stroke onset, except for two participants in the control group (C7 and C12, less than three months). The time after stroke onset did not statistically differ between the groups (W = 49, p-value = .08), but the control group had a relatively shorter onset time than that of the motivation group.

Participant's behaviors for autonomy support:

Task difficulty parameter and personal mastery experience: Figure 3A and 3B represent changes in the task difficulty parameter (TDP) for the time limit across training sessions.

As expected, the TDP of the control group was randomized across the training sessions. Conversely, each motivation group selected different TDPs over time. Both groups showed decreases in TDP (i.e., increases in task difficulty) from the early to late phases (t = -3.332, p = .001, effect size = .02, Figure 3C). However, the TDP of the motivation group was always lower than that of the control group (t = -3.22, p = .01, effect size = .28). Successful experience did not change in the control group (t = -2.186, p = .129) but dramatically increased in the motivation group (t = -10.21, p < .0001, effect size with omega = .10)(Figure 3D). While unsuccessful experiences (failure when using the more-affected arm) significantly decreased in the control group (t = 4.846, p <.0001), they marginally increased in the motivation group (t = -2.508, p = .059)(Figure 3E). Success rates increased during late training in both groups (t = 15.503, p <.0001) but did not differ between groups (t = 1.02, p =.306)(Figure 3F).

Changes in IMES and clinical variables before and after intervention

Training effects on impairment, performance, and use measured by IMES

We compared impairment, performance, and use of the more-affected arm measured by IMES before and after the training sessions and between the motivation and control groups using the mixed-effect model (Table 2, Figure 4). The impairment represented by the average movement duration was faster after the IMES training sessions than before, but it reached a marginally significant level for both groups (t = -1.782, p= .07, effect size = .07). Performance, which was measured in the forced-choice block of the fast-time constraint condition, was significantly higher in the retention test than in the baseline test for both groups (t = 7.562, p < .0001, effect size = .68). However, there were no group differences in impairment (t =-.981, p = .326), or performance (t = .620, p = .902) (Figure 4 A & B).

The use was measured by the number of successful movements by the more-affected arm in the free-choice block under the fast-time constraint condition. The results revealed an interaction between the Group and Test variables. Post-hoc tests showed that the use of the more-affected arm did not improve in the control group, even after the training sessions (t = -.859, p =.826). However, the motivation group showed a dramatic increase in the use of the more-affected arm after the training (t = -5.983, p < .0001). Neither group differed in their use at the baseline test (t = .686, p = .902), but significantly differed in the retention test (t = -3.179, p = .014, Figure 4C).

Training effects on impairment, performance, and use measured by clinical outcome measure

We performed the same comparison for impairment, performance and use, but with the clinical outcome measures (Table 2, Figure 4). The total FMA scores increased after training in both groups (t = 5.047, p <.0001, effect size = .48), while log-transformed WMFT – time significantly decreased after training in both groups (t = -3.418, p <.001, effect size = .28). However, the control and motivation groups did not differ in terms of FMA (t = -.719, p =.472) or WMFT time (t = .716, p = .474)(Figure 4 D&E). The AAUT QOM score did not change after training, (t=-.207, p= .836) and two groups did not differ (t = -.754, p = .451)(Figure 4F). Note that AAUT AOU data are not shown as AAUT AOU revealed the same results as those of AAUT QOM.

Training effects on SE and OE

Both SE and OE increased from baseline to the retention tests for both groups (t = 3.029, p =.002, effect size = .23, for SE; t = 11.426, p = <.0001, effect size = .44, for OE, Table 2). However, these changes did not differ across groups (t = .091, p =.927 for SE, t = .254, p = .799 for OE, Figure 4 G&H, Table 2).

Correlation between changes in successful experience during training and changes in IMES as well as clinical and motivation variables before and after training

We investigated whether successful experience affects impairment, performance, and use of the more-affected arm. Specifically, we performed a correlation analysis between changes in the successful experience between the early and late phases of the training sessions, and changes in impairment, performance and use. We found a significant and strong correlation between the changes in the use of the more-affected arm measured by the IMES and the changes in successful experience (rho = .48, p = .014, Figure 5C). However, none of the others measured by IMES, clinical tests, and motivational variables (i.e., SE, and OE) were correlated (Spearman correlation, all p > .05).

Discussion

Our results can be summarized in three aspects. 1) The motivation group utilized autonomy support, and thus the patients in the group selected more difficult tasks across training sessions (i.e., TDP significantly decreased over the training blocks, Figure 3C). 2) The training sessions helped improve impairment (MD in IMES, and FMA in clinical tests, Figure 4A and Figure 4D), performance (performance in IMES, and WMFT in clinical tests, Figure 4B, and Figure 4E), motivation (SE, and OE, Figure 4 G&H). 3) The patients in the motivation group showed increased successful experiences (Figure 3D) and increased use of the more-affected arm (Figure 4C) measured by IMES after the training sessions compared to those in the control group; however, impairment, performance and motivation questions did not differ between groups. The two measures (successful experience and use of the more-affected arm) were strongly associated (Figure 5C); a more successful experience may lead to more use.

Successful experience enhances the use of the more-affected arm

In real life, when people experience successful movements for a particular task, their confidence in that activity increases, and consequently, their behaviors are strengthened.[17] Our results revealed that patients with stroke who underwent successful movement using the more-affected arm during choice training were more likely to select their more-affected arm.

We investigated the belief that confidence level is the key to behavioral changes, as the confidence level was measured by SE and OE. However, in our study, they were not strongly associated with the use of the more-affected arm per se. Although both control and motivation groups enhanced SE and OE after training, they did not differ between the two groups despite different training protocols (Figure 4G and H). However, as noted above, the use of the more-affected arm was significantly higher in the motivation group than in the control group after training (Figure 4C). Additional analyses also revealed that changes in motivation variables (e.g., SE and OE) were not correlated with changes in the use of the more-affected arm (r = 446, p =.101, spearman, data is not shown).

Our findings contradict the previous study suggesting that SE is significantly linked to the more-affected UE selection; the higher the self-efficacy, the greater the use of that arm.[10–12] If this was applied to our study, since SE increased in both groups, the use of the more-affected arm should have increased in both groups. However, this was not the case in this study. To explain this discrepancy, we need closely examine the success rates and failure experiences. Even though the success rates increased after the training sessions, they did not differ between groups (Figure 3F), as SE and OE did (Figure 4G and H). Participants in the two groups showed different strategies for improving their success rates. The participants in the control group performed training conservatively. They did not explore or extend the use of the more-affected arm; instead, they tried to diminish the failure experience, as shown in Figure 3E. Thus, the overall success rate increased, but the overall successful experience remained the same before and after training. Conversely, participants in the motivation group became less sensitive to failure over time. Consequently, they had more successful experiences using the more-affected arm during training, leading to increased use of that arm. That is, participants in the motivational group increased their success rates after the training sessions.

In summary, a more successful experience itself may directly lead to more use, instead of additional motivational variables such as SE and OE. The statistically significant and strong correlation between the changes in successful experience and in- use supports this idea.

Role of autonomy support in the rehabilitation

What makes a difference to successful experiences? What makes a difference in learning arm use patterns? This may be a form of support for autonomy. In our study, the results of the motivation group revealed that a successful personal mastery experience accomplished by autonomy support increased their use measured by the IMES. Due to the instruction and training environment related to autonomy support, the patients in the motivation group were aware of the training goal of using the more-affected arm as much as possible. Accumulated successful experience via autonomy support may make the affected arm habitual. In other words, since successful experience increased only in the motivation group, and since successful experience leads to an increase in the use of the more affected arm, more autonomy support may lead to increased use of the more affected arm.

The motor learning literature reveals that giving learners control over certain aspects of practice conditions enhances motor skill learning.[26] In our study, high repetitive reaching movements without autonomy support mitigated motor impairment and improved motor performance, but these gains were not transferred to the more-affected arm. This result is in line with a previous study, that is, ASAP participants with autonomy support showed higher use of the more-affected arm, measured by MAL, than the usual care immediately after training. Motor impairment and performance, however, improved in both groups; there were no group differences.[9,27] Autonomy support selectively affects the use of the more-affected arm, while training itself affects its impairment and performance.

The participants in the motivation group selected a shorter time limit (decreased task difficulty TDP, Figure 3B and C), whose target disappeared quickly as the experiment progressed. Why did the motivational group choose a more challenging task? This may be because completing challenging tasks result in greater internal rewards than completing easy tasks.[28] In this case, it is crucial that the participants successfully complete a challenging task and not just a challenging task.[29] Thus, successful experiences during the current training block in our study might increase satisfaction and competence in the reaching task, resulting in selecting the more challenging task for the next training block.

These results may support that our IT device-based system, IMES, provides the rehabilitation framework of autonomy support with reduced loads of clinicians and is successful in quantifying task difficulty with the objective measure, that is, TDPs in the time limit.

Discrepancy between IMES and clinical tests

In our study, the performance and motivational variables (e.g., self-efficacy and outcome expectation) increased regardless of whether the stroke patients conducted the training with or without autonomy support. However, we only observed an increase in the use of the more affected arm with autonomy support, as measured by the IMES. (Figure 4C). We did not find any group or training effects on using the more affected arm when measuring the AAUT clinical test (Figure 4F). This may be due to the nature of task-specific motor learning. Unlike previous studies, in which participants were trained with task-oriented practice emphasizing real-world activities,[7,9] we involved a simple reaching task during the training; thus, the gains in IMES did not spread to the clinical test. Nevertheless, one can confirm that even with a simple reaching task with an IT device, autonomy support is practical for impairment mitigation, performance enhancement, and use of the more-affected UE in post-stroke patients. Further studies with IT devices involving autonomy support and training for instrumental use of the more affected arm may be able to show the distinguishable effect of autonomy support on real-world arm choices.

Limitations

This study had several limitations. First, we included only a small number of participants in each group. Owing to COVID 19, it was difficult to recruit patients with stroke for training for a relatively long period. Three participants in the control group interrupted the experiments for one month due to the hospital lockdown, while all participants in the motivation group were recruited after the onset of COVID 19. Therefore, we could not ignore the impact of COVID on our results because there were unusual constraints such that the patients in the hospital could not meet their family or go outside when they wanted. However, the Jeonju city in which we conducted the experiments was not in pandemic and had very rare infection of the COVID. In addition, none of our participants with stroke were infected during the entire experimental schedule. Therefore, fear of COVID 19 was not as serious as that in other countries. Second, unlike other studies, we did not use imaging data in this study. The posterior parietal cortex and premotor cortex are the centers for the decision making, including the arm selection. We were unable to monitor the changes in blood activity levels in these areas before and after the choice training. Lastly, people commonly use the arm and hands in a bimanual fashion, and often each arm and hand have different roles for certain tasks (e.g., writing on a note, writing with the right hand, and holding the paper with the left hand). However, we did not train our participants with stroke via either symmetrical or asymmetrical bimanual movement. Furthermore, our training was a reaching task, which was different from the typical real-world use of arm and hand movements (e.g., reaching and manipulating objects). A large

sample size with imaging data and a comparison of treatment protocols between forced choice and free choice training are needed for future research.

Conclusion And Implications

Successful experience via autonomy support leads to an increase in the use of the more affected arm after stroke. A successful experience during the early training phase is required for patients to understand the importance of using the more-affected arm. Consequently, they may be able to use the arm more habitually. In addition, autonomy support combined with an IT device is practical for impairment mitigation, performance enhancement, and use of the more-affected UE in post-stroke patients. Thus, developing IT devices involving autonomy support and instrumental use of the more-affected arm will show a distinguishable effect of autonomy support on real-world arm choice.

Declarations

Ethics approval and consent to participate

This study was conducted at Jeonju University and was approved by the Institute of Research Board of the Jeonju University(jjIRB–190414–HR–2019-0409). All participants read and signed a written consent form before starting the experiment.

The potential risks and benefits of participation in this study were explained to each participant in advance.

Consent for publication

All participants provided signed informed consent for the publication of this study.

Competing interests

The authors declare that they have no competing interests.

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Author's contributions

SK and CEH researched conceptualization or article/hypothesis generation and planned the methods to generate the hypothesis. SN, YS, and YJ conducted experiments, managed patients, and organized and reported data. SK and CEH analyzed the results, and SK, CEH, SN, and YS wrote the original manuscript and prepared all figures. All authors reviewed and edited the manuscript. All authors read and approved the final manuscript.

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References

1. Sterr A, Freivogel S, Schmalohr D. Neurobehavioral aspects of recovery: Assessment of the learned nonuse phenomenon in hemiparetic adolescents. Arch Phys Med Rehabil [Internet]. 2002;83:1726–31. Available from: http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12474177
2. Hidaka Y, Han CE, Wolf SL, Winstein CJ, Schweighofer N. Use it and improve it or lose it: Interactions between arm function and use in humans post-stroke.PLoS Comput Biol. 2012;8.
3. Taub E, Crago JE, Burgio LD, Groomes TE, Cook EW, DeLuca SC et al. an Operant Approach To Rehabilitation Medicine: Overcoming Learned Nonuse By Shaping. J Exp Anal Behav [Internet]. 1994;61:281–93. Available from: http://doi.wiley.com/10.1901/jeab.1994.61-281

4. Taub E, Uswatte G, Mark VW, Morris DM. The learned nonuse phenomenon: Implications for rehabilitation. Eura Medicophys [Internet]. 2006;42:241–55. Available from: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=med5&NEWS=N&AN=17039223
5. Winstein CJ, Wolf SL, Dromerick AW, Lane CJ, Nelsen MA, Lewthwaite R et al. Interdisciplinary Comprehensive Arm Rehabilitation Evaluation (ICARE): A randomized controlled trial protocol. BMC Neurol [Internet]. 2013;13:5. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3547701&tool=pmcentrez&rendertype=abstract
6. Bosch J, O'Donnell MJ, Barreca S, Thabane L, Wishart L. Does Task-Oriented Practice Improve Upper Extremity Motor Recovery after Stroke? A Systematic Review. ISRN Stroke. 2014;2014:1–10.
7. Lang CE, Strube MJ, Bland MD, Waddell KJ, Cherry-Allen KM, Nudo RJ et al. Dose response of task-specific upper limb training in people at least 6 months poststroke: A phase II, single-blind, randomized, controlled trial. Ann Neurol [Internet]. 2016;80:342–54. Available from: https://onlinelibrary.wiley.com/doi/10.1002/ana.24734
8. Winstein C, Kim B, Kim S, Martinez C, Schweighofer N. Dosage Matters: A Phase IIb Randomized Controlled Trial of Motor Therapy in the Chronic Phase after Stroke. Stroke. 2019;50:1831–7.
9. Lewthwaite R, Winstein CJ, Lane CJ, Blanton S, Wagenheim BR, Nelsen MA et al. Accelerating Stroke Recovery: Body Structures and Functions, Activities, Participation, and Quality of Life Outcomes From a Large Rehabilitation Trial. Neurorehabil Neural Repair [Internet]. 2018;32:150–65. Available from: http://journals.sagepub.com/doi/10.1177/1545968318760726
10. Chen Y-A, Lewthwaite R, Schweighofer N, Monterosso JR, Fisher BE, Winstein C. The Essential Role of Social Context and Self-Efficacy in Daily Paretic Arm/Hand Use after Stroke: An Ecological Momentary Assessment Study with Accelerometry. Arch Phys Med Rehabil [Internet]. Elsevier Inc.; 2022; Available from: https://doi.org/10.1016/j.apmr.2022.09.003
11. Chen S, THE INFLUENCE OF SELF-EFFICACY ON RECOVERY OF SPONTANEOUS, ARM USE IN HEMIPARETIC STROKE by A Dissertation Presented to the FACULTY OF THE USC GRADUATE SCHOOL. In Partial Fulfillment of the Requirements for the Degree DOCTOR OF PHILOSOPHY (BIOKINESIOLOGY). 2011
12. Chin LF, Hayward KS, Brauer SG. Factors Influencing Paretic Upper Limb Use During First 4 Weeks After Stroke. Am J Phys Med Rehabil [Internet]. 2021;100:153–60. Available from: https://journals.lww.com/10.1097/PHM.0000000000001539
13. Wulf G, Lewthwaite R. Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. Psychon Bull Rev [Internet]. Psychonomic Bulletin & Review; 2016;23:1382–414. Available from: http://dx.doi.org/10.3758/s13423-015-0999-9
14. Bandura A. Self-efficacy: Toward a unifying theory of behavioral change. Psychol Rev [Internet]. 1977;84:191–215. Available from: http://doi.apa.org/getdoi.cfm?doi=10.1037/0033-295X.84.2.191
15. Hooyman A, Wulf G, Lewthwaite R. Impacts of autonomy-supportive versus controlling instructional language on motor learning. Hum Mov Sci [Internet]. 2014;36:190–8. Available from: https://linkinghub.elsevier.com/retrieve/pii/S016794571400061X
16. Reeve J, Tseng C-M. Cortisol reactivity to a teacher's motivating style: the biology of being controlled versus supporting autonomy. Motiv Emot [Internet]. 2011;35:63–74. Available from: http://link.springer.com/10.1007/s11031-011-9204-2
17. Taub E, Uswatte G, Elbert T. New treatments in neurorehabiliation founded on basic research. Nat Rev Neurosci. 2002;3:228–36.
18. Lang CE, MacDonald JR, Gnip C. Counting repetitions: An observational study of outpatient therapy for people with hemiparesis post-stroke. J Neurol Phys Ther. 2007;31:3–10.
19. Stoloff RH, Taylor JA, Xu J, Ridderikhoff A, Ivry RB. Effect of reinforcement history on hand choice in an unconstrained reaching task. Front Neurosci [Internet]. 2011 [cited 2013 Sep 21];5:41. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3066466&tool=pmcentrez&rendertype=abstract
20. Ballester BR, Maier M, San Segundo Mozo RM, Castada V, Duff A, Verschure PFMJ. Counteracting learned non-use in chronic stroke patients with reinforcement-induced movement therapy. J Neuroeng Rehabil. 2016;13:74.
21. Fugl Meyer AR, Jaasko L, Leyman I. The post stroke hemiplegic patient. I. A method for evaluation of physical performance. Scand J Rehabil Med [Internet]. 1975;7:13–31. Available from: http://www.ncbi.nlm.nih.gov/pubmed/1135616
22. Albert ML. A simple test of visual neglect. Neurology. 1973;23:658–64.
23. Park H, Kim S, Winstein CJ, Gordon J, Schweighofer N. Short-Duration and Intensive Training Improves Long-Term Reaching Performance in Individuals with Chronic Stroke. Neurorehabil Neural Repair [Internet]. 2016;30:551–61. Available from: http://nnr.sagepub.com/content/early/2015/09/22/1545968315606990.abstract
24. Kim S, Park H, Han CE, Winstein CJ, Schweighofer N. Measuring habitual arm use post-stroke with a bilateral time-constrained reaching task. Front Neurol. 2018;9:1–5.

25. Han CE, Kim S, Chen S, Lai YH, Lee JY, Osu R et al. Quantifying arm nonuse in individuals poststroke. Neurorehabil Neural Repair [Internet]. 2013 [cited 2013 Sep 21];27:439–47. Available from: http://journals.sagepub.com/doi/10.1177/1545968312471904
26. Sanli EA, Patterson JT, Bray SR, Lee TD. Understanding self-controlled motor learning protocols through the self-determination theory. Front Psychol [Internet]. 2013;3. Available from: https://www.ptonline.com/articles/how-to-get-better-mfi-results
27. Winstein CJ, Wolf SL, Dromerick AW, Lane CJ, Nelsen MA, Lewthwaite R, et al. Effect of a task-oriented rehabilitation program on upper extremity recovery following motor stroke the ICARE randomized clinical trial. JAMA - J Am Med Assoc. 2016;315:571–81.
28. Harter S. Pleasure Derived from Challenge and the Effects of Receiving Grades on Children ' s Difficulty Level Choices Author (s): Susan Harter Published by: Wiley on behalf of the Society for Research in Child Development Stable URL. Child Dev. 1976;49:788–99. http://www.jstor.org/stabl.
29. Lomas D, Patel K, Forlizzi JL, Koedinger KR. Optimizing challenge in an educational game using large-scale design experiments. Conf Hum Factors Comput Syst - Proc [Internet]. New York, NY, USA: ACM; 2013. p. 89–98. Available from: https://dl.acm.org/doi/10.1145/2470654.2470668

Tables

Table 1. Demographic information for control and motivation groups (N=26)

Variable		Control (n =12)	Motivation (n = 14)	p-value
Age		62.17±5.84	61.14±12.93	.793
Stroke types	Hemorrhage	7	7	
	Infarction	5	7	
Affected side	Left	5	4	
	Right	7	10	
Gender	Female	2	3	
	Male	9	11	
Stroke month		29.83±28.26	56.43±48.56	.08
FMA-UE[a]		47±12.64	42±17.28	.643
MMSE[b]		28.58±1.78	29.36±1.01	.302
Edinburgh[c]		92.50±10.55	97.14±7.26	.156
[a]FM-UE: Fugl Mayer Assessment-Upper extremity, [b]MMSE-K: Mini Mental State Examination-Korean, [c] EHI: Edinburgh Handedness Inventory				

Table 2. Motivation and clinical variables before and after intervention

		Control			Motivation			
		Baseline	Retention	P	Baseline	Retention	P	Group p
IMES variables	Impairment	.62± .27[a]	.61± .3	P=.07	.64±.23	.48 ± .13	P=.07	.326
	Performance	17.75±12.1	27.92±13.61	<.001***	17.79±12.03	33.57±12	<.001***	.902
	Use	**15.92±18.56**	**21.67±16**	**.826**	**10.36±18.26**	**47.43±26.92**	**<.001*** **	**<.001*** **
Clinical variables	Fugl-meyer Assessment	45.92±12.24	50±10.57	<.001***	42.00 ± 17.28	45.64 ± 16.86	<.001***	.472
	Wolf motor function test	.63±.21	.51±.11	<.001***	.71 ± .34	.56 ± .20	<.001***	.474
	Actual amount of use test(QOM)	2.21±1.2	2.30±1.21	.836	1.9 ± 1.53	1.86 ± 1.39	.836	.451
Motivation variables	self-efficacy(SE)	57.10±20.21	67.38±26.77	.002**	55.76 ± 28.45	70.34 ± 23.47	.002**	.927
	Outcome expectation(OE)	53.65±22.45	67.18±25.69	<.001***	52.48 ± 27.02	72.87 ± 20.58	<.001***	.799

[a] Mean±Standard Deviation, *p<.05, ** p<.01, *** p<.001

Impairment in IMES variables was represented as a log-transformed movement duration and performance and use in IMES variables were represented as a total number of successful reaching by the more-affected arm.

Figures

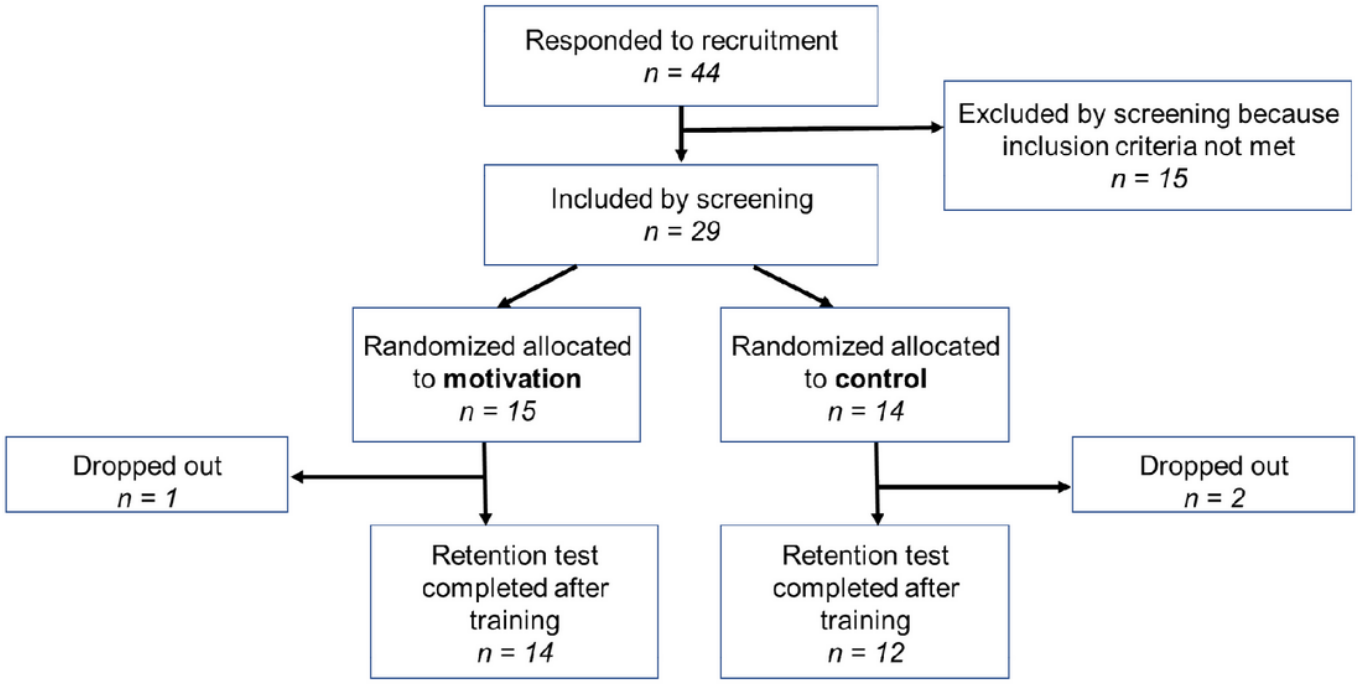
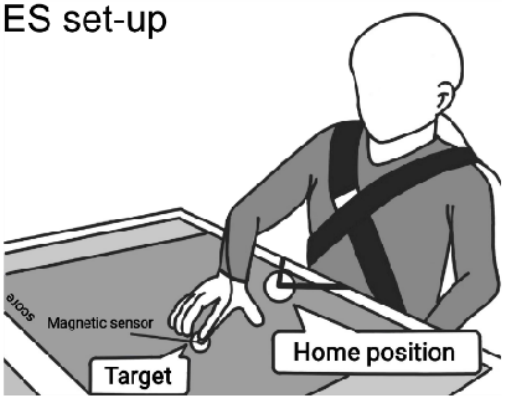


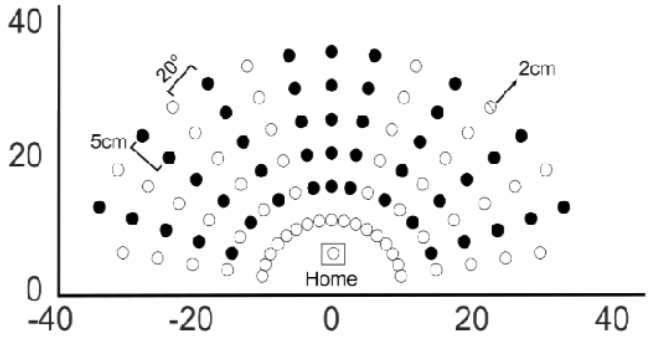
Figure 1

ONSORT (Consolidated Standards of Reporting Trials) diagram for the present study.

A. IMES set-up



B. Target locations



C. Test conditions and blocks

Condition	Choice block		
No-time constraint	Free	Forced LA (Impairment, MD)	Forced MA (Impairment, MD)
Fast-time constraint	Free (Use)	Forced LA	Forced MA (Performance)

D. Experimental schedule

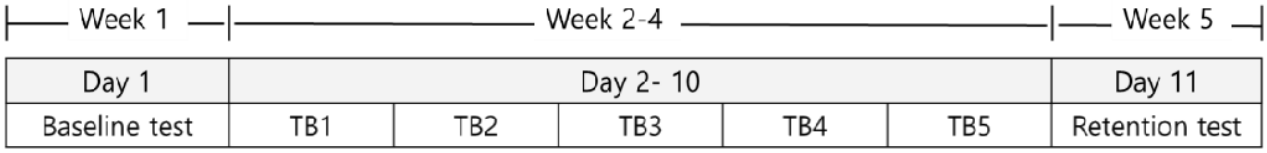


Figure 2

A. The 55-inch touchscreen was placed on the table to adjust the height. The participant sat on the chair, and the trunk was constrained with a belt to prevent compensational movement. All participants were able to reach the farthest target by adjusting the table height. B. One hundred target locations were predefined for the training session. Forty-five targets (filled circles) were used for the test session. C. IMES test conditions and blocks. IMES had a test session with and without a time limit. Each condition had free- and forced-choice blocks and forced-choice blocks started from the less-affected (LA) arm to the more-affected (MA) arm. Movement duration (MD) for each arm was measured during these blocks. D. Experiment schedule. The first and last weeks were the baseline and retention tests, and the middle three weeks were training sessions conducted three times per week. TB, training block.

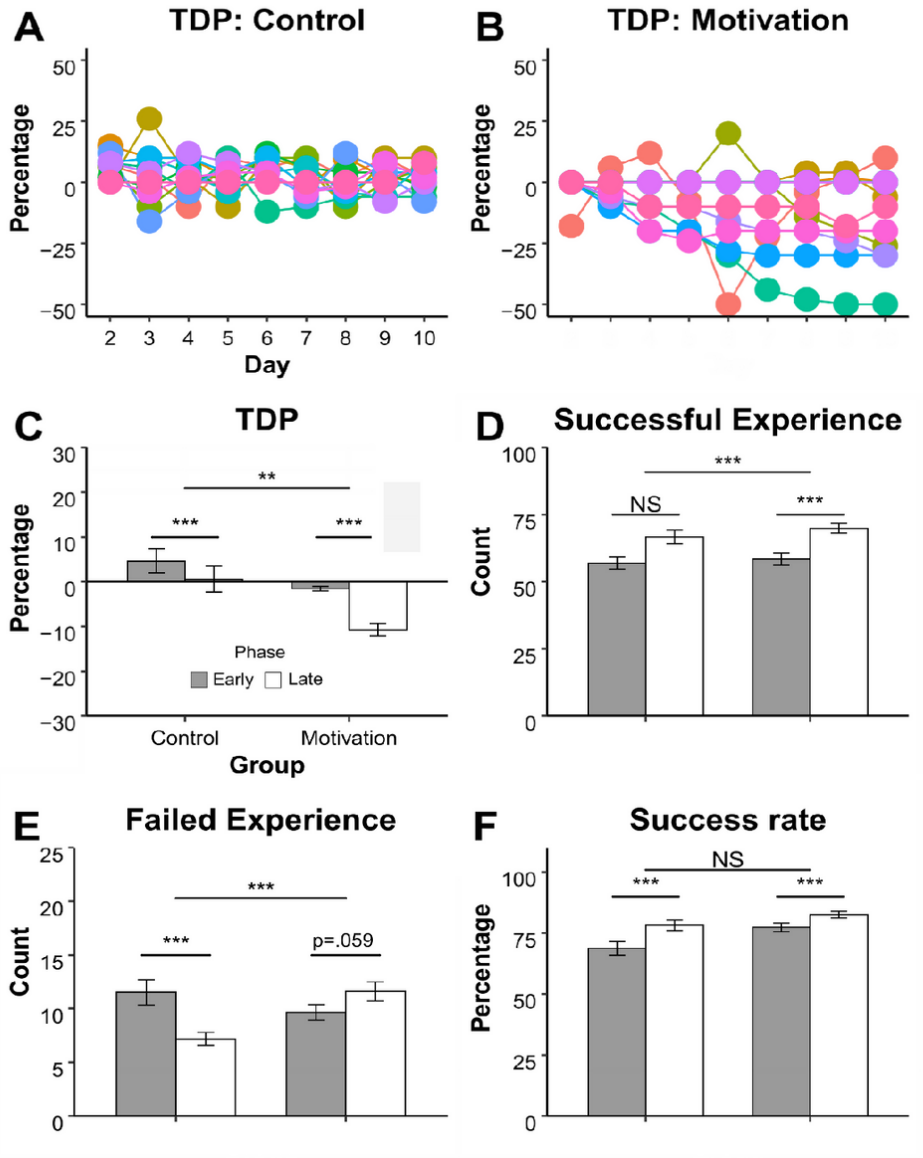


Figure 3

The task difficulty parameter (TDP) for the time limit and successful experience during training sessions. A-B. The individual TDP across training sessions in the control (A) and the motivation (B) groups. The averaged TDP and successful experience in early and late phases were shown in C and D, respectively. The failed experience and success rate in the early and late phases were shown in E and F, respectively. Although the TDP was lower in the motivation group than the control group, the successful experience was significantly higher in the motivation group than the control group. NS: non-significant, **p < .01, ***p < .001.

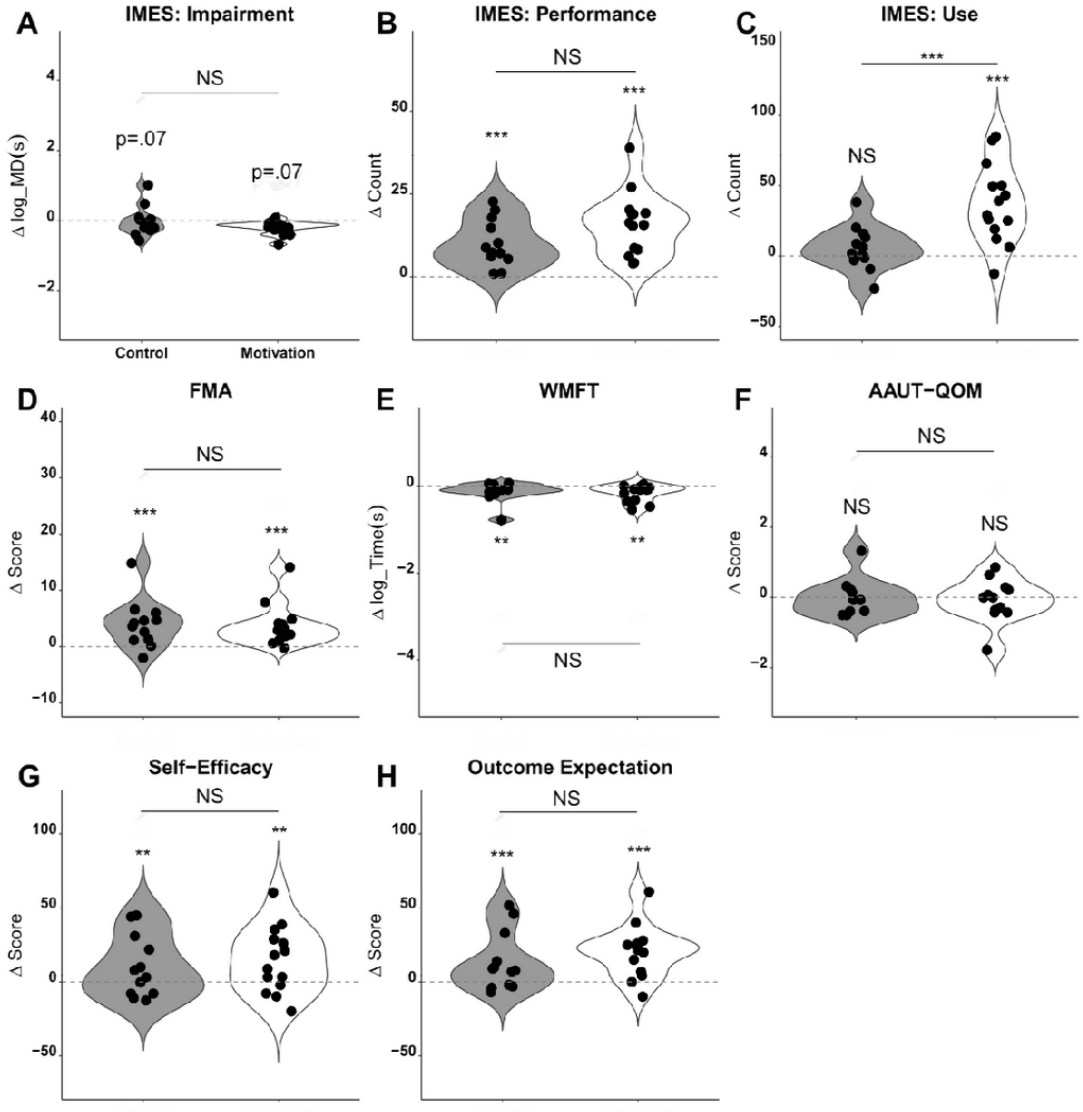


Figure 4

Group comparison between the motivation and control groups for changes in IMES variables (A-C), clinical variables (D-F), and motivation variables (G-H) after the training. Each dot represented each participant, and gray and white violin plots represented the control and motivation groups. Baseline-Retention test differences in movement duration(A), performance which was measured in the forced-choice block in IMES(B), FMA (D), WMFT(E), SE(G), and OE(H) were significantly different from zero, but there were no group differences. Change in the use of the more-affected arm measured in the free-choice block in IMES(C) was higher in the motivation group after the training. Still, AAUT-QOM(F) change did not differ between baseline and retention tests or between control and motivation groups. NS: non-significant, * $p < .05$, ** $p < .01$, *** $p < .001$.

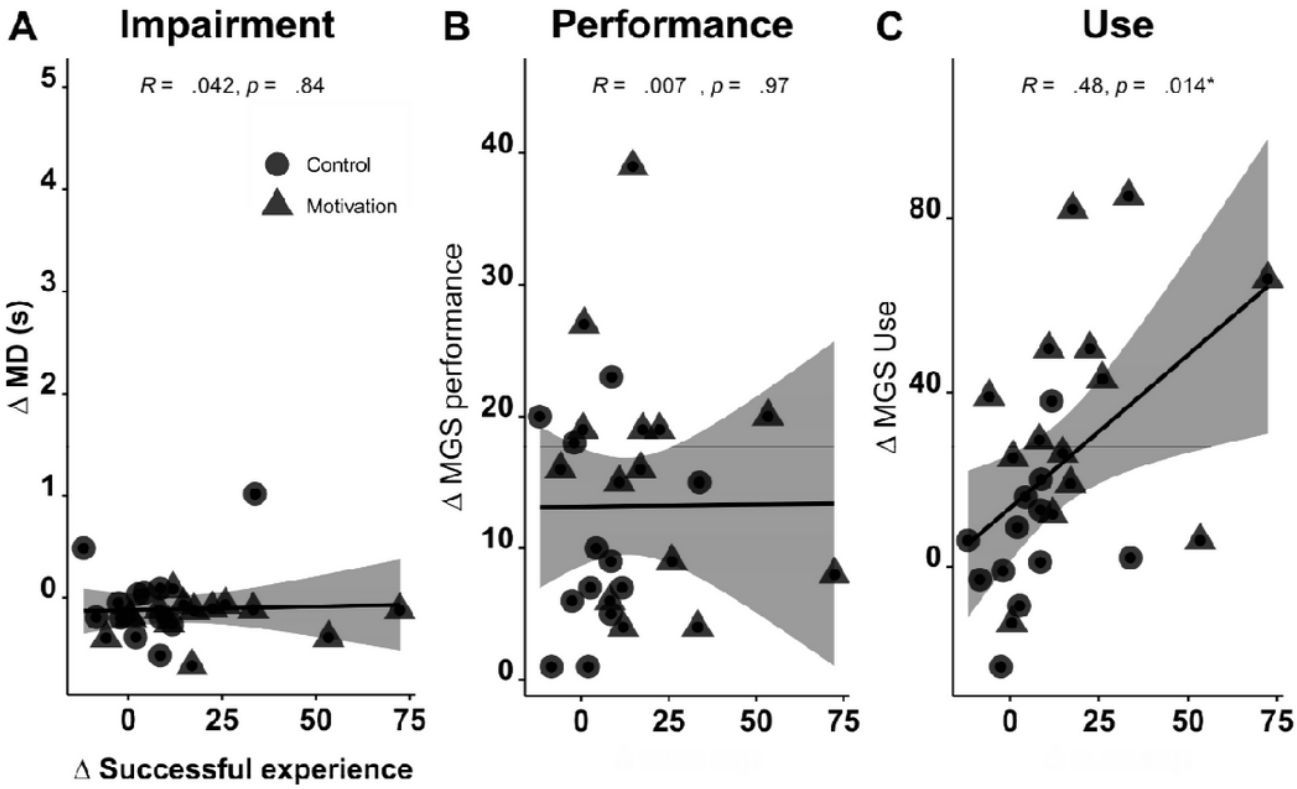


Figure 5

The correlations between changes in successful experience and variables in IMES. Impairment(A) and performance(B) did not correlate with successful experience. However, the change in the use of the more-affected arm was significantly correlated with the changes in the successful experience (C)(p = .014). Each data point represents each individual in both control and motivation groups.