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Review Article

Overview of Effects of Motor Learning Strategies in Neurologic and Geriatric Populations: A Systematic Mapping Review

Li-Juan Jie, PhD [a,*], Melanie Kleynen, PhD [a,*], Guus Rothuizen, MSc [a], Elmar Kal, PhD [b,c], Andreas Rothgangel, PhD [a], Susy Braun, PhD [a]

[a] *Research Centre for Nutrition, Lifestyle and Exercise, School of Physiotherapy, Zuyd University of Applied Sciences, Faculty of Health, Heerlen, The Netherlands.*
[b] *College of Health, Medicine and Life Sciences, Brunel University London, London, UK.*
[c] *Centre for Cognitive Neuroscience, Brunel University London, London, UK.*

KEYWORDS
Analogy learning;
Discovery learning;
Dual-task learning;
Errorless learning;
Mapping review;
Motor learning;
Movement imagery;
Observational learning;
rehabilitation;
Systematic review;
Trial-and-error learning

Abstract *Objective:* To provide a broad overview of the current state of research regarding the effects of 7 commonly used motor learning strategies to improve functional tasks within older neurologic and geriatric populations.
Data Sources: PubMed, CINAHL, and Embase were searched.
Study Selection: A systematic mapping review of randomized controlled trials was conducted regarding the effectiveness of 7 motor learning strategies—errorless learning, analogy learning, observational learning, trial-and-error learning, dual-task learning, discovery learning, and movement imagery—within the geriatric and neurologic population.
Data Extraction: Two thousand and ninety-nine articles were identified. After screening, 87 articles were included for further analysis. Two reviewers extracted descriptive data regarding the population, type of motor learning strategy/intervention, frequency and total duration intervention, task trained, movement performance measures, assessment time points, and between-group effects of the included studies. The risk of bias 2 tool was used to assess bias; additionally, papers underwent screening for sample size justification.

List of abbreviations: ADL, activities of daily living; CINAHL, cumulative Index to Nursing and Allied Health Literature; MCID, minimally clinically important differences; RCT, randomized controlled trial; RoB2, risk of bias 2 (tool); TIDieR, Template for Intervention Description and Replication.
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* Jie and Kleynen have contributed equally to this work.

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Data Synthesis: Identified articles regarding the effects of the targeted motor learning strategies started around the year 2000 and mainly emerged in 2010. Eight populations were included, for example, Parkinson's and stroke. Included studies were not equally balanced: analogy learning (n=2), errorless learning and trial-and-error learning (n=5), mental practice (n=19), observational learning (n=11), discovery learning (n=0), and dual-tasking (n=50). Overall studies showed a moderate-to-high risk of bias. Four studies were deemed sufficiently reliable to interpret effects. Positive trends regarding the effects were observed for dual-tasking, observational learning, and movement imagery.

Conclusions: Findings show a skewed distribution of studies across motor learning interventions, especially toward dual-tasking. Methodological shortcomings make it difficult to draw firm conclusions regarding the effectiveness of motor learning strategies to improve functional studies. Future researchers are strongly advised to follow guidelines that aid in maintaining methodological quality. Moreover, alternative designs fitting the complex practice situation should be considered.

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Motor learning—defined as a relatively permanent change in performance or behavior[1]—plays a central role in the rehabilitation of neurologic and geriatric rehabilitation.[2-4] Health care professionals, such as physical and occupational therapists, support patients to acquire or relearn a broad range of different motor skills, for example, walking or reaching, to help them regain independence in activities of daily living (ADLs).[1-4] Certain general principles of skill training, like the frequency and specificity of practice and number of repetitions, are now widely recognized as being crucial to effective rehabilitation. In the last 2 decades, evidence has accumulated to suggest that *how* skills are taught may also be of relevance,[5,6] and guidelines now recommend incorporating motor learning strategies into treatment approaches to improve rehabilitation success.[7] However, in many cases, there remains a lack of clear guidance on how different motor learning strategies can best be incorporated (and which can best be used for whom).[7-9] The vast array of motor learning strategies available to health care professionals, combined with the rapid increase in publications and the lack of comprehensive overviews on the effectiveness of these different strategies, makes it challenging to make informed decisions regarding the appropriate treatment approach. Further, many health care professionals seem to acquire novel knowledge unsystematically and in a fragmented manner.[9,10]

In order to support clinicians' decision-making and aid the evidence-based implementation of motor learning strategies in their clinical practice, Kleynen et al[11] developed a practical framework based on the broad distinction between conscious and nonconscious attributes of the motor learning process. This distinction proposes that implicit motor learning targets more nonconscious attributes of the motor learning process, whereas explicit motor learning targets more conscious attributes of the motor learning process.[12,13] The framework includes 7 common motor learning strategies, which have been categorized as promoting more implicit or explicit motor learning: errorless learning, dual-task learning, analogy learning, discovery learning, observational learning, movement imagery, and trial-and-error learning (see Supplemental appendix S1).[11,14] The implicit—explicit distinction is often used as a departure point within explanatory models of motor learning and proposes that implicit motor learning targets more nonconscious attributes of the motor learning process, whereas explicit motor learning targets more conscious attributes of the motor learning process.[15] The framework was informed by practice-based evidence from experts in different fields (eg, researchers, health care professionals) as well as by research results that underpin these different learning strategies' working mechanisms. Currently, most evidence regarding the effectiveness of more implicit and explicit forms of motor learning is based on studies using laboratory tasks, for example, Kal et al.[16] To support health care professionals in making informed decisions about the use of the 7 motor learning strategies, more insight into their effectiveness in functional tasks is needed.

Systematic reviews potentially provide therapists with an accessible overview of available evidence to support their decision-making process. However, these reviews are often limited to a single motor learning strategy (eg, errorless learning) within specific target populations (eg, pathology- or disease-based) and focus on a single measurement outcome to allow data pooling or synthesis (eg, see[17-19] for excellent examples). In clinical practice, however, therapists treat various populations with a great variety of motor problems (and thus outcomes), rehabilitation needs, and preferences. Therapists therefore may need to switch between strategies, both within and between patients, to provide an optimal learning environment—but lack clear guidance to base this on as a more comprehensive overview of the motor learning literature is lacking. This study aimed to perform a systematic mapping review of randomized controlled trials (RCTs) to provide a comprehensive overview of the effects across the 7 motor learning strategies incorporated in motor learning framework by Kleynen et al[11] for neurologic and geriatric populations. In addition, the content of the interventions is described to gain more insight into how therapists could perform the different strategies in clinical practice.

Methods

This systematic review was conducted in 2 parts. The first part consisted of quantitative analysis and focused on mapping the included studies to gain a quick overview of how many were published per (sub)population and motor learning strategy over time. The second part included a descriptive analysis of motor learning intervention contents and effects, critically appraised in light of the studies' risk of bias and sample size justification.

Eligibility criteria

The population included all adults older than 60 and was not restricted to certain disorders. However, to optimize the search strategy, potentially relevant populations were specifically included in the search function (see Search Strategy). To ensure that the included studies would have direct clinical relevance, the aim of these studies should be a performance improvement in a functional movement task. We defined a functional task as an activity that individuals perform as part of their daily routine, work, hobbies, or rehabilitation program. The control intervention group (comparator) was not predefined. The eligibility criteria for the selection of studies are presented in table 1.

Search strategy

Two researchers (L.J., G.R.) searched the databases PubMed, CINAHL, and Embase for RCTs using the mentioned combination of key search terms: aging (older adults) OR neurologic diseases (stroke OR Parkinson OR dementia) AND motor learning strategies (analogy learning OR errorless learning OR trial-and-error OR discovery learning OR dual-task learning OR action observation OR mental practice) AND ADL (functional tasks). A detailed overview of the search strategy and the search terms used can be found in Supplemental appendix S2. Additionally, reference tracking of the included studies was performed to identify additional studies.

Study selection process

Identification and screening of studies

Two researchers (G.R., L.J.) independently screened all retrieved articles from the databases based on the title, abstract, and keywords. After screening, the same 2 researchers obtained and assessed the full text of eligible articles independently according to the predefined selection criteria. In case of persistent disagreement, a third reviewer (M.K.) was consulted to reach a consensus.

Risk of bias assessment and sample size justification

The Cochrane Risk of Bias 2 (RoB2[20]) was used to evaluate 5 different domains of bias, namely randomization, deviations from the intended intervention, missing outcome data, measurements of the outcome, and reporting of results. Based on specific criteria for each domain, an overall risk of bias was determined for every study, ranging from low risk of bias (green) to some concerns (yellow) to high risk of bias (red). Given the large number of studies included a total of 7 assessors (L.J., M.K., G.R., A.R., E.K., S.B., R.S.) were involved in rating the risk of bias. To increase the reliability of the ratings, 4 calibration sessions were organized in which each item was discussed and further specified for the context of this study. Each article was assessed by 2 independent assessors. In case of disagreements, a third researcher was consulted. The authors of the included studies were not contacted to retrieve missing information. In addition to the standard RoB2 items, 1 extra item regarding the studies' sample sizes was added because appropriate sample size justifications are often lacking or not transparently described.[21] Studies were also evaluated based on whether an a priori power analysis or other form of sample size justification was described. If sample size justification was described and achieved, this was categorized as "green." If no appropriate size justification was provided or the required sample size was not achieved, this was categorized as "red."

Data extraction

The mentioned characteristics were extracted: year of publication, author, number of participants in total and per intervention/control group, population studied, sex, mean age, movement task trained, type of motor learning strategy/intervention, frequency and total duration of supervised practice, movement performance measures, assessment time points, and between-group effects.

Table 1 Overview of selection criteria

	Inclusion	Exclusion
Population	Mean ≥ 60 y	Mean age < 60 y
Intervention	Errorless learning, analogy learning, observational learning, trial-and-error learning, dual-task learning, discovery learning, and mental imagery	Multimodal training interventions to ensure training effects are because of 1 of the 7 interventions rather than other training modalities or combined interventions
	≥1 training session	<1 training session
Outcome	Physical movement performance outcome assessed immediately after the intervention (acquisition) and/or at a delayed time point (retention/ transfer)	No motor performance outcome was measured, eg, only magnetic resonance imaging or electroencephalogram. No serial reaction time outcomes
Study design	Randomized controlled trial	Any other non-randomized trial design
Language	English, German, or Dutch	-
Accessibility	-	No full text available

Data analyses and synthesis

The analysis was divided into (1) a quantitative analysis in which the current available studies were mapped (Q1-Q3) and (2) a descriptive analysis of the studies' characteristics, the content of the intervention, and synthesis of the potential effects (Q4). For the quantitative analysis, all eligible articles were included. In the descriptive analysis, to increase the reliability of this study's conclusion regarding intervention effects, a second selection took place in which studies were excluded if they scored "high" on RoB2 and lacked (or failed to meet) an appropriate sample size justification.

As part of the quantitative analysis, a flowchart was presented to visualize the search and selection procedure. Further, the number of included studies per learning strategy over time and the type of patient population per learning strategy were mapped. An overview table per learning strategy was created presenting the risk of bias (low, some concerns, or high), sample size justification (yes/no), population, number of participants, and task trained.

As part of the descriptive analysis, more in-depth information was provided regarding the population (type, group sizes, sex, age), intervention (motor learning strategies, control intervention[s]), duration and frequency, task trained, movement performance measurement, and measurement moments (eg, immediately after the intervention and, if applicable, also at follow-up). In the last step, we descriptively synthesized between-group differences, both in terms of significance and direction of effects.

Results

Study selection

The study flow is visualized in figure 1. In total, 2099 articles were identified. After deleting duplicates and screening the titles and abstracts, 236 articles remained, of which 5 articles could not be retrieved. The full text of 231 articles was obtained, and after screening, 90 were considered eligible and included for further analysis. Within this sample, there were 3 occasions in which the data of 1 single RCT was analyzed in 2 different papers.[22-26] These papers were counted once, leading to a grand total of 87 studies included in the current review.

Quantitative analysis (mapping)

In total, 87 studies were included. Six of the 7 motor learning strategies were addressed (fig 2). The most frequently described motor learning strategies were dual-task learning (n=50 studies), mental practice (n=19), and action observation (n=12); no studies were found for discovery learning within these target populations. In total, 8 different populations were identified within the included studies (fig 2). Figure 3 visualizes the number of studies published for each learning strategy over time.

An overview of the risk of bias scores, power, group size, tasks, and between-group differences is reported in table 2. Of the 87 studies, 5 scored well on both the RoB (low) and sample size justification,[27-31] while 18 had a high RoB and did not report a sample size justification.[32-49] Included studies' group sizes ranged from 6 to 161 participants.

Descriptive analysis

Sixty-nine studies were left for the descriptive analyses, the results which are presented below per learning strategy.

Analogy learning

One study was included, with a sample size of 79 participants.[29] The task trained in the experimental group was walking in community-dwelling individuals after stroke. The practiced gait parameters were chosen based on the patients' preferences and needs, as well as the clinical expertise of the therapists involved in the trial. The analogy learning instructions were personalized based on the individual's walking impairment and preferences. The effectiveness of analogy learning was compared to an explicit motor learning intervention. No between-group differences were observed either postintervention or at the follow-up (low RoB, appropriate sample size justification). The intervention's duration was 3 weeks. The total intensity of training (ie, the number of sessions multiplied by the duration of each session) was 270 minutes over 9 sessions. See Supplemental table S1 for more details.

Errorless learning and trial and error

Three studies were included, with a total of 251 participants, the sample sizes per study ranged from 30 to 161. Two included persons with Alzheimer's, of which 1 trained in ADL activities that were based on the patients' preferences and needs,[50] and the other practiced a functional arm-hand task from the Action Programme test.[51] Furthermore, another study included participants with transtibial amputations and trained in the right technique for fitting a prosthetic limb.[52] The effectiveness of errorless learning was examined in comparison to trial and error (n=3).

The errorless learning intervention was structured in different ways. Frequent feed-forward instructions (ie, "how to do") were provided before the initiation of the task. To minimize mistakes, some studies also provided cues verbally or pictorially.[33,51] In contrast to the errorless learning intervention, in the trial-and-error studies, participants were allowed to make mistakes and self-correct their performance.[50] In some studies, open-ended questions about the task were posed to participants when repeated mistakes were observed for example: "what went wrong during your performance?" "How would you fix this?".

One study[51] observed between-group differences in favor of the errorless learning intervention at the follow-up measurement; however, there are some concerns about RoB and a lack of sample size justification. Another study[52] observed between-group differences postintervention (some concerns about RoB, and appropriate sample size justification). One study[50] did not observe any between-group differences (low RoB, the proposed sample size was not met in intention-to-treat analyses).

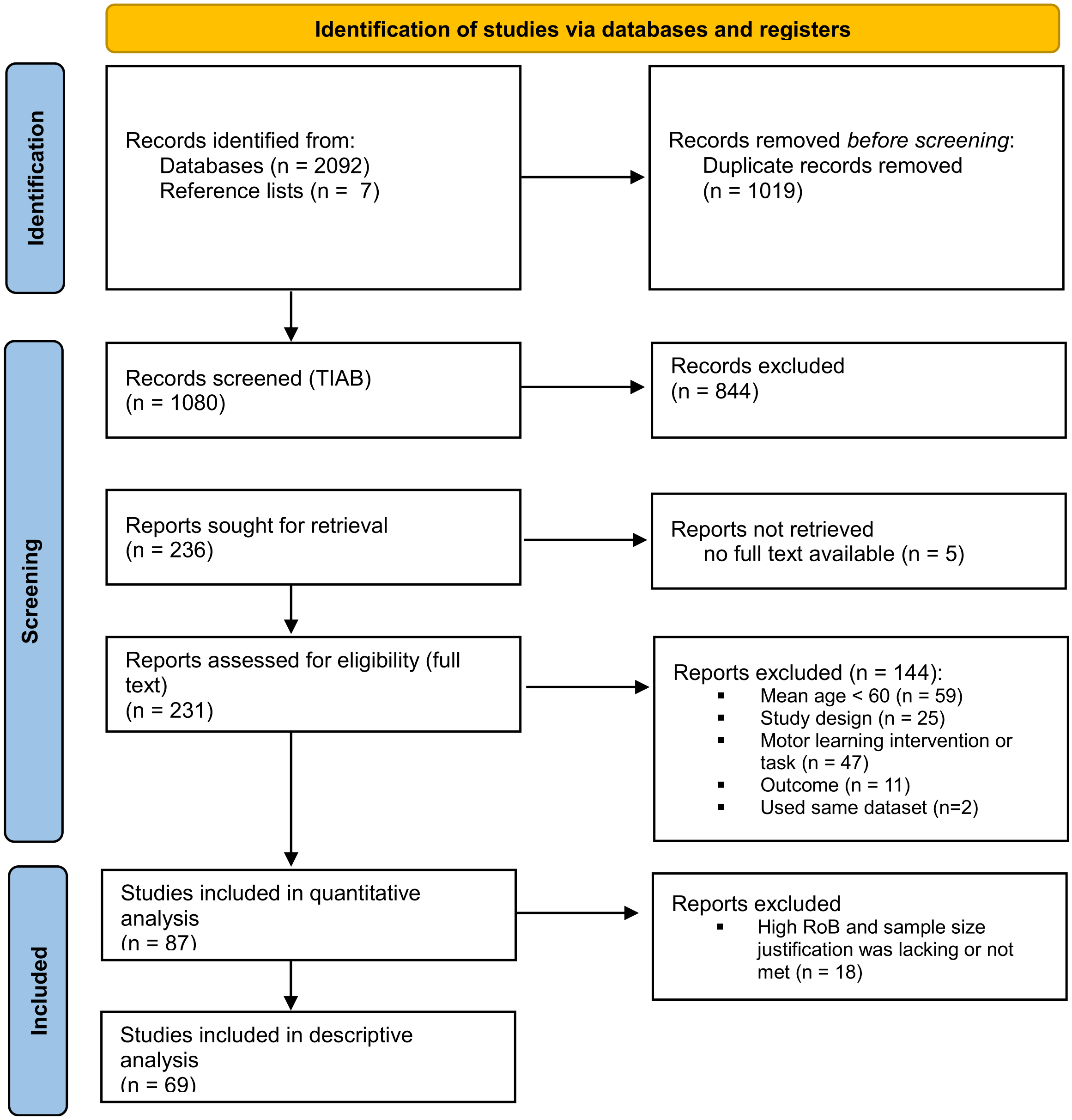

Fig 1 PRISMA flowchart for the inclusion of studies.

The total study duration of these interventions ranged from 1 single session[51,52] up to 10 weeks.[50] The total intensity of training (ie, the number of sessions multiplied by the duration of each session) ranged from 15 to 30 minutes in 1 session[52] to 540 minutes over 10 training sessions.[50] Kessels and Olde Hensken[51] did not specify the amount of time spent in each session. See Supplemental table S2 for more details.

Mental practice

Eleven studies were included, with a total of 407 participants, sample sizes per study ranged from 11 to 121 participants. Two of these included people with Parkinson's, both focusing on gait.[53,54] One included participants after total knee arthroplasty and practiced knee extension.[55] Eight studies included people after stroke, 2 focusing on gait,[56,57] 3 on upper limb activities,[43,58,59] 2 on daily life activities,[60-62] and 1 on sit-to-stand transfers.[63] The effectiveness of mental practice was examined in comparison to relaxation (n=2), care as usual (n=5), cognitive exercises (or mental rehearsal; n=3), and standardized activities for the upper limbs (n=1). Additionally, 2 studies specifically described that the intervention included a demonstration-then-practice element.

Mental practice interventions were often based on standardized protocols, scripts, or frameworks. The different stages of the mental practice intervention often included familiarization with the task (eg, analysis of the task sequence) and mental practice aspects (eg, kinematic components), followed by internal imagery, mental rehearsal, and overt task performance. Two studies used audio instructions; while in one other study, the mental practice intervention was guided by a computer program. Different types of mental practice reported in the studies included kinesthetic, visual, and motivational imagery.

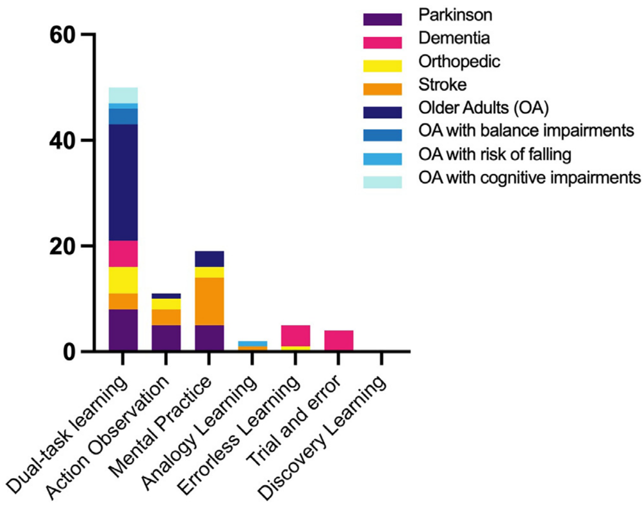

Fig 2 Visualization of the number of studies identified per learning strategy including the subpopulations covered.

One study[61] observed between-group differences in favor of the intervention postintervention and at the follow-up measurement (some concerns about RoB, and sample size justification lacking). Five others[54,55,59,62,63] observed between-group differences in favor of the mental practice intervention postintervention (RoB ranged from some concerns to high, one with appropriate sample size justification). Three[53,58,60] did not find any between-group differences (all with some concerns about RoB, 2 with appropriate sample size justification), and one[56] did not calculate any between-group differences.

The total study duration of these interventions ranged from 3 weeks[56,61,62] up to 6 weeks.[59] The total intensity of training (ie, the number of sessions multiplied by the duration of each session) ranged from 180 minutes over 12 sessions[56] to 900 minutes over 15 training sessions.[61,62] Braun et al[53,60] did not specify the amount of time spent in each session. See Supplemental table S3 for more details.

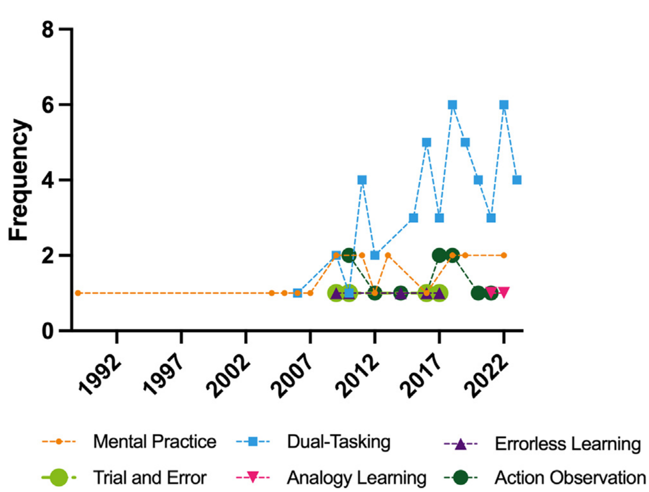

Fig 3 The year of publication per motor learning strategy. The identified motor learning strategies are based on the 7 best-known and most-used motor learning strategies as embedded in the framework of Kleynen et al.[11] Data of 6 motor learning strategies were included, as no studies for discovery learning were identified.

Observational learning

Eleven included studies, with a total of 481 participants, sample sizes per study ranged from 18 to 102 participants. Three involved people after stroke who only practiced upper limb activities.[64-66] Five focused on people with Parkinson's, focusing on gait in general (n=1)[67] or freezing of gait in particular (n=4).[26,68-70] Two included orthopedic patients in which daily activities,[71] mobilization exercises, and transfers[72] were trained. One included older adults who practiced walking.[73]

In all studies, observational learning was combined with or integrated into different types of functional training. In all studies, observational learning was applied through watching short movies of the task, exercise, or strategy to be learned. One study used videos that were composed of images and sounds (sonification).[26] Most studies (n=9) investigated the effects of observing functional movements in comparison to observation of landscape videos or abstract pictures.[64,66-73] Two studies compared observational learning to a functional training intervention without (action) observation.[65,74]

Four studies[64,66,73,74] observed between-group differences in favor of the action observation intervention postintervention and at the follow-up measurement (all with some concerns about RoB, 3 with appropriate sample size justification). Five others[65,68,69,71,72] observed between-group differences in favor of the intervention at either of the measurement points (all with some concerns about RoB, 2 with appropriate sample size justification). One[67] did not find any between-group differences (some concerns about RoB, and appropriate sample size justification), and one[70] did not calculate any between-group differences.

The total study duration of these interventions ranged from 8 days[67] up to 8 weeks.[74] The total intensity of training (ie, the number of sessions multiplied by the duration of each session) ranged from 432 minutes over 18 sessions[71] to 960 minutes over 16 training sessions.[74] Jaywant et al[67] did not specify the amount of time spent in each session. See Supplemental table S4 for more details.

Dual-task learning

Forty-three studies were included, with a total of 2306 participants, sample sizes per study ranged from 12 to 134. Three involved persons after stroke: 2[75,76] practiced walking and 1[77] focused on daily life activities. Three included orthopedic patients, who all practiced balance exercises.[48,78-80] Five studies included persons with dementia, focusing on walking and/or balance tasks.[81-85] Six studies included people with Parkinson's: 2 focused on balance training,[86,87] 3 on walking,[27,35,88] and 1 on aquatic exercises.[22] Seventeen included older adults: 13 practiced walking and/or balance exercises,[28,31,49,89-98] while the remainder engaged in aerobic exercises,[99] stepping exercises,[100] resistance training,[101] stationary biking,[102] or agility and strength training.[103] Three studies included older adults with balance impairments and practiced walking and/or balance.[25,103-105] One included older adults with fall histories and practiced walking and balance.[106] Three targeted older adults with cognitive impairments, focusing on walking and/or balance[107,108] or dancing.[30]

Within the dual-task conditions, the secondary task was either a motor or a cognitive task. Secondary motor tasks included (avoiding) obstacles, carrying or playing with obstacles (eg, a grocery bag, a tray, rattle, umbrella, or

Table 2 Risk of bias scores, power, group size, task, and overall outcome of the included studies

Population	Reference	Overall RoB2	Power	Group Size	Task*	Difference Between Groups	
Analogy learning							
Stroke	Jie et al[29]	+	+	N=79	Walking	Post: NS	Follow-up: NS
Older adults with risk of falling	Mak et al[39]	−	−	N=56	Walking	Post: NS	Follow-up: NS
Errorless learning							
Orthopedic	Donaghey et al[52]	!	+	N=30	Arm-hand function ability	Post: S (2/5 outcomes)	Follow-up: NA
Alzheimer's	Bourgeois et al[33]	−	−	N=74	ADL	Post: NS	Follow-up: NS
	Thivierge et al[47]	−	−	N=17	ADL	Post: NS	Follow-up: NS
	Kessels and Olde Hensken[51]	!	−	N=60	Arm-hand function ability	Post: S (1/1 outcome)	Follow-up: S (1/1 outcome)
	Voigt-Radloff et al[50]	+	−	N=161	ADL	Post: NS	Follow-up: NS
Mental practice							
Parkinson's	Braun et al[53]	!	+	N=47	Walking and sit-to-stand	Post: NS	Follow-up: NS
	da Silva et al[46]	−	−	N=18	Walking and balance	Post: NS	Follow-up: NA
	El-Wishy et al[54]	!	−	N=26	Walking	Post: S (6/6 outcomes)	Follow-up: NA
	Santiago et al[45]	−	−	N=20	Walking	Post: NS	Follow-up: NS
	Monteiro et al[40]	−	−	N=14	Mobility and balance	Post: S (3/3 outcomes)	Follow-up: NA
Older adults	Batson et al[32]	−	−	N=6	Dynamic exercises	Post: NS	Follow-up: NA
	Linden et al[38]	−	−	N=23	Walking balance	Post: NS	Follow-up: NA
	Nicholson et al[42]	−	−	N=30	Walking (obstacle course)	Post: NS	Follow-up: NA
Orthopedic	Korbus and Schott[37]	−	−	N=29	Wrist movements	Post: NS	Follow-up: NA
	Paravlic et al[55]	−	+	N=34	Knee extension	Post: S (8/11 outcomes)	Follow-up: NA
Stroke	Braun et al[60]	!	−	N=36	Multiple functional tasks	Post: NS	Follow-up: NS
	Dickstein et al[56]	!	+	N=23	Walking	Post: NR	Follow-up: NR
	Guerra et al[57]	−	+	N=16	Walking, standing up	Post: NS	Follow-up: NA
	Ietswaart et al[58]	!	+	N=121	Upper limb activities	Post: NS	Follow-up: NA
	Liu et al[61]	!	−	N=46	ADL tasks	Post: S (3/5 outcomes)	Follow-up: S (1/1 outcomes)
	Liu et al[62]	!	−	N=35	ADL tasks	Post: S (5/8 outcomes)	Follow-up: NA
	Malouin et al[63]	!	−	N=12	Standing up and sitting down	Post: S (2/2 outcomes)	Follow-up: NS
	Page et al[59]	!	−	N=11	Upper limb ADL	Post: S (1/2 outcomes)	Follow-up: NA
	Park et al[43]	−	−	N=30	Upper limb activities through Wii games	Post: S (3/3 outcomes)	Follow-up: NA
Observational learning							
Orthopedic	Bellelli et al[71]	!	−	N=60	Daily actions with the leg or trunk	Post: S (6/9 outcomes)	Follow-up: NA
	Villafañe et al[72]	!	−	N=31	Mobilization exercises & transfers	Post: S (3/10 outcomes)	Follow-up: NA

(*continued*)

Table 2 (*Continued*)

Population	Reference	Overall RoB2	Power	Group Size	Task*	Difference Between Groups	
Parkinson's	Agosta et al[68]	!	−	N=25	Strategies to circumvent FoG	Post: S (1/9 outcomes)	Follow-up: NS
	Jaywant et al[67]	!	+	N=23	Walking	Post: NS	Follow-up: NA
	Mezzarobba et al[26,74]	!	+	N=22	Strategies to circumvent FoG	Post: S (5/19 outcomes)	Follow-up 1: S (8/19 outcomes) Follow-up 2: S (8/19 outcomes)
	Pelosin et al[69]	!	−	N=18	Strategies to circumvent FoG	Post: NS	Follow-up: S (2/6 outcomes)
	Pelosin et al[70]	!	−	N=64	Strategies to circumvent FoG	Post: NR	Follow-up: NR
Stroke	Franceschini et al[64]	!	+	N=102	Functional upper limb activities	Post: S (1/7 outcomes)	Follow-up: S (1/7 outcomes)
	Sale et al[66]	!	−	N=67	Functional upper limb activities	Post: S (4/6 outcomes)	Follow-up: S (4/6 outcomes)
	Mancuso et al[65]	!	−	N=36	Functional upper limb activities	Post: S (1/4 outcomes)	Follow-up: NA
Older adults	Rojasavastera et al[73]	!	+	N=33	Walking	Post: S (2/6 outcomes)	Follow-up: S (2/6)
Dual task learning							
Stroke	An et al[77]	!	−	N=30	ADL	Post: S (1/1 outcomes)	Follow-up: NA
	Fishbein et al[75]	!	−	N=22	Gait training	Post: NS	Follow-up: NA
	Meester et al[76]	!	−	N=50	Walking	Post: NS	Follow-up: NA
Orthopedic	Conradsson and Halvarsson[78]	−	+	N=68	Balance training program	Post: S (10/32 outcomes)	Follow-up: NA
	Karagül et al[36]	−	−	N=43	Balance exercises	Post: S (4/10 outcomes)	Follow-up: NA
	Konak et al[79]	!	+	N=42	Static and dynamic balance	Post: S (3/6 outcomes)	Follow-up: NA
	Uzunkulaoğlu et al[80]	!	+	N=50	Balance training program	Post: NS	Follow-up: NA
	Vaillant et al[48]	−	−	N=56	Walking and balancing	Post: S (1/4 outcomes)	Follow-up: S (1/4 outcomes)
Dementia	Chen et al[81]	!	−	N=28	Walking	Post: NS	Follow-up: NS
	Ghadiri et al[82]	!	+	N=38	Walking and manipulative skills	Post: S (2/9 outcomes)‡	Follow-up: S (2/ 9 outcomes)‡
	Lemke et al[83]	+	−	N=105	Walking and balance	Post: S (25/55 outcomes)	Follow-up: S (10 /55 outcomes)
	Menengiç et al[84]	!	+	N=20	Simple chair-based exercises	Post: S (4/6 outcomes)	Follow-up: NA
	Schwenk et al[85]	!	−	N=61	Walking and balance	Post: S (1/2 outcomes)	Follow-up: NA
Parkinson's	Fernandes et al[86]	!	−	N=15	Balance training	Post: S (2/5 outcomes)	Follow-up: NA
	Geroin et al[27]	+	+	N=121	Gait and functional training	Post: S (14/26 outcomes)	Follow-up: S (14/26 outcomes)
	Jäggi et al[87]	!	+	N=40	Balance and coordination	Post: NS	Follow-up: NA
	Park et al[44]	−	−	N=12	Drumming	Post: S (1/13 outcomes)	Follow-up: NA
	da Silva et al[22,23]	!	−	N=25	Aquatic exercise	Post: S (4/6 outcomes), NR (2/6 outcomes)	Follow-up: S (4/6 outcomes), NR (2/6 outcomes)
	do Nascimento Silva et al[35]	−	−	N=10	Gait and balance training	Post: NS	Follow-up: NA
	Valenzuela et al[109]	!	+	N=40	Gait training	Post: S (11/20 outcomes)	Follow-up: Post: S (11/23 outcomes)
	Yang et al[88]	!	+	N=18	Gait training	Post: S (2/21 outcomes)	Follow-up: NA

(*continued*)

Table 2 (*Continued*)

Population	Reference	Overall RoB2	Power	Group Size	Task*	Difference Between Groups	
Older adults	Brustio et al[89]	!	+	N=60	Balance and walking	Post: NS	Follow-up: NA
	Pessoa et al[92]	!	−	N=30	Walking and balance exercises	Post: S (3/6 outcomes)	Follow-up: NA
	Gregory et al[99]	!	+	N=44	Aerobic exercises	Post: S (3/6 outcomes)	Follow-up: S (3/6 outcomes)
	Hiyamizu et al[90]	!	−	N=36	Strength and balance training	Post: NS	Follow-up: NA
	Javadpour et al[28]	+	+	N=69	Balance training	Post E1 vs C: S (10/10 outcomes) Post E2 vs C: S (9/10 outcomes)	Follow-up: NA
	Kitazawa et al[100]	!	−	N=60	Step exercise program	Post: NS	Follow-up: NA
	Castillo de Lima et al[34]	−	−	N=16	Agility training	Post: NS	Follow-up: NA
	Nascimento et al[91]	!	+	N=44	Walking and balancing	Post: NR	Follow-up: NA
	Nematollahi et al[41]	−	−	N=44	Balancing	Post: NS	Follow-up: NA
	Norouzi et al[101]	!	−	N=60	Resistance training	Post E1 vs E2 & C: S (1/1 outcome)	Follow-up E1 vs E2 & C: S (1/1 outcome)
	Plummer-D'Amato et al[93]	!	−	N=17	Walking and balancing	Post: NS	Follow-up: NA
	Raichlen et al[102]	!	+	N=74	Stationary biking	Post: NS	Follow-up: NA
	Sinaei et al[94]	!	−	N=24	Balance training	Post: NS	Follow-up: NA
	Tasvuran Horata et al[95]	−	+	N=32	Walking and balancing	Post: S (5/8 outcomes)	Follow-up: NA
	Trombetti et al[31]	+	+	N=134	Balance training	Post: S (8/17 outcomes)	Follow-up: NA†
	Uemura et al[103]	!	−	N=15	Agility and strength	Post: NR	Follow-up: NA
	Wollesen et al[98]	!	−	N=38	Walking and Balancing	Post: S (7/36 outcomes)	Follow-up: NA
	Wollesen et al[96]	!	+	N=78	Walking and balancing	Post: S (8/22 outcomes)	Follow-up: NA
	Wollesen et al[97]	−	+	N=95	Walking and balancing	Post: S (3/12 outcomes)	Follow-up: NA
	Yamada et al[111]	−	+	N=84	DVD group training	Post: S (1/4 outcomes)	Follow-up: NA
	Yamada et al[110]	!	+	N=53	DVD group training	Post: NR	Follow-up: NA
	You et al[49]	−	−	N=13	Gait training	Post: NR	Follow-up: NA
Older adults with balance impairments	Azadian et al[104]	!	−	N=30	Gait training and balancing	Post E1 & E2 vs C: S (5/13 outcomes) Post E2 vs E1 & C: S (3/13 outcomes)	Follow-up: NA
	Khan et al[105]	!	−	N=39	Balance training	Post: S (2/4 outcomes)‡	Follow-up: NA
	Silsupadol et al[24,25]	!	+	N=21	Balance training	Post E1 & E2 vs C: S (2/10 outcome) Post E1 vs E2 & C: S (1/10 outcome)	Follow-up: NA
Older adults with history of falls	Park et al[106]	!	+	N=58	Walking and balance training	Post: S (2/2 outcomes)	Follow-up: NA
Older adults with cognitive impairments	Delbroek et al[107]	!	−	N=20	BioRescue balance training	Post: NR	Follow-up: NA
	Kuo et al[108]	!	+	N=30	Walking	Post: E1 & E2 vs C: S (4/20 outcomes)	Follow-up: E2 vs C: S (4/20 outcomes)
	Parial et al[30]	+	+	N=60	Dancing	Post: NR	Follow-up: NR

Abbreviations: ADL, activities of daily living; C, control group; FoG, Freezing of Gait; NA, not applicable; NR, not reported; NS, not significant ($P>.05$); S, significant ($P<.05$).

* Task trained in experimental conditions.

† Cross-over trial.

‡ Effects in favor of the control group

musical instruments), exercises with a ball (eg, bouncing, passing, throwing, catching, holding, kicking) practicing daily life activities such as (un)buttoning a shirt, putting beans in a container (nondominant hand), unscrewing a nut and bolt, and drawing a letter on the floor with one of their feet. Secondary cognitive tasks included engaging in conversations; singing; arithmetic tasks (eg, 2-forward and 3-backward calculations); repeating animals' names; reading words or sentences backward; counting/reciting the days of week; simple word games (eg, coming up with a word that starts with the last letter of the previous word or naming as many words starting with the letter P (or another random letter); remembering cards; repeating phrases; playing phonemic word chain games; reciting a poem; answering questions about the participants' orientation to a person (identifying their name), time (date, month, or year), and place (current location); reacting to virtual situations (eg, you're in a taxi but do not have your wallet); explaining the order of wearing clothes (eg, dress, skirt, shirt, tie); talking about daily routines; making a shopping list; categorization (eg, types of land animals, drinks, colors, objects, names of boys and girls names, flowers, vegetables, fruit); clock face task; alternative uses (eg, name an object and come up with alternative uses for that object); a creativity task (eg, name as many objects that you know that are tall); letter fluency task; planning; singing a song; comparing drawings and naming differences; word spelling (fast as possible); auditory Stroop task; remembering shapes and colors; responding to auditory cues (fast as possible); and paying attention to tripping hazards. Finally, secondary tasks presented through Virtual Reality games, for example, playing a ball game, reactive boxing game, or cleaning windows.

Eight studies observed between-group differences[27,46,82,83,101,108,109] in favor of the dual-task learning intervention postintervention and at the follow-up measurement (2 studies with low RoB, 6 with some concerns about RoB, 3 with appropriate sample size justification). Nineteen[25,28,31,77-79,84-86,88,92,95-98,104-106,110] observed between-group differences only immediately after the intervention (2 with low RoB, 13 with some concerns about RoB, 4 with high RoB, 13 with appropriate sample size justifications). Eleven[75,76,80,81,87,89,90,93,94,100,102] did not observe any between-group differences (all with some concerns about RoB, 3 with appropriate sample size justifications). Five studies[30,35,103,107,111] did not report the between-group effects (1 with low RoB, 4 with some concerns about RoB, 3 with appropriate sample size justifications).

The total study duration of these interventions ranged from 1 day[92] up to 26 weeks.[31,99] The total intensity of training (ie, the number of sessions multiplied by the duration of each session) ranged from 40 minutes in 1 session[92] to 4875 minutes over 65 training sessions.[99] See Supplemental table S5 for more details.

Discussion

This systematic mapping review provides a broad overview of the available studies on 7 motor learning strategies, including their effect on improving functional tasks in neurologic and geriatric populations. In total, 87 studies were identified, covering 6 of the 7 included motor learning strategies. The most frequently researched motor learning strategies were dual-task learning (n=50 studies), mental practice (n=19), and action observation (n=12). No studies were found for discovery learning.

Overview of available studies

Mapping the publications gave more insight into the development of publications over time and the distribution and quality of RCTs regarding the 7 strategies and different target groups. In the early 1980s, new scientific insights were published regarding recovery mechanisms and neuroplasticity of the brain, which fueled interest in the potential role of motor learning in rehabilitation.[112] Research on the effects of motor learning strategies to improve functional tasks started around the year 2000, with studies on mental practice and publications increasing substantially from 2010 on. In general, there seems to be quite a big delay between the discovery of a learning strategy's (potential) working mechanisms and its evaluation in applied research through RCTs. For example, the mirror-neuron system and its role in our ability to learn by imitating others was discovered in the early 1990s,[113,114] but it took about 20 years before the effects were evaluated within rehabilitation. Comparably, Mellit and Petit[115] showed through fMRI that during imagery and performance of a motor skill, almost the same brain areas are active, which gave a huge impulse for research on movement imagery in sports. However, it was not until 2007 that an increase in studies within (neuro)rehabilitation was seen.

Based on the results of our Delphi study,[15] we expected the number of included studies to be (somewhat) equally balanced across the motor learning strategies. After all, a substantial number of experts had identified these 7 motor learning strategies as the "most used and well-known" strategies within their field. This was, however, not the case. By far, dual-task learning has been examined the most. There are several reasons which may explain why. First, dual-tasking is highly prevalent in daily life activities and needs to be practiced as such in every context (specificity).[116] Additionally, some of the first clinical studies conducted showed very promising results[24,25,28] which might have led to an increase in similar, repetitive research paradigms: in 38 of the 50 included studies, walking or balance was trained using a secondary cognitive task. Interestingly, no studies on the use of discovery learning were included (1 was excluded during the screening process). And only 2 studies on analogy learning fulfilled our inclusion criteria.[29,39] This may be explained by the fact that analogy learning is a relatively new concept, which was first translated to rehabilitation in 2014 for persons after stroke[117] and with Parkinson's disease.[29,39,118] Trial-and-error learning was not researched as the experimental intervention in the included studies but was only used as a control condition for errorless learning in 4 studies. This is contrary to other fields of research (eg, children, sports), in which trial-and-error learning and discovery learning have been assessed more extensively.[119]

Although the target population was defined broadly in our search and inclusion criteria, motor learning strategies were studied in only 5 populations. Older adults (without other specific motor or cognitive problems) were the most researched, followed by persons with Parkinson's disease and after stroke. No studies were found on other neurologic diseases such as multiple sclerosis, spinal cord injury, or traumatic brain injury. Within the included population, certain motor learning strategies appeared to be preferred over others. Errorless learning, for example, was almost exclusively researched in persons with dementia, dual-task learning was mostly studied in older adults, and mental practice was often used in studies to improve arm-hand ability in people after stroke. Based on clinical expertise, these strategies may be seen as more suitable for these specific populations, but evidence for their effects is still unclear.

A critical finding of this review is the limited methodological rigor observed across the 87 included studies. Specifically, only 5 studies (6%) had a low risk of bias and justified and achieved their desired sample size. Most of the studies scored "some concerns" (54 studies; 62%). The lack of a strong methodological foundation in many studies makes it difficult to reliably identify the true intervention effects.[120] We also noted that the interpretation of individual study findings was frequently inaccurate (eg, solely reported within-group differences and/or interaction effects without reporting between-group differences). There seems to be a more general problem of regulating the risk of bias and ensuring the accuracy of the reporting within motor learning research.[121,122]

Effects of the 7 motor learning strategies

Only 4 (5% of total) studies were deemed reliable enough to interpret the effects reported, based on their RoB2 (category green; low RoB), sample size justification (category green), and reporting of between-group differences: Geroin et al[27] found between-group differences for dual-task gait and functional training in persons with Parkinson's, Trombetti et al[31] and Javadpour et al[28] found between-group differences for dual-task balance training in older adults, and Jie et al[29] did not find significant between-group differences in gait for analogy learning in persons after stroke. Within the remaining moderately reliable studies, there seems to be a clear positive trend favoring observational learning across various populations (8/11 studies), when applied in addition to care as usual. Within mental practice (8/19 studies) and dual-task learning (27/43 studies), between-group effects favoring the intervention group were found in about half and most of the included studies, respectively. For dual-task learning, some trends may be observed within populations, as between-group effects in favor of the dual-task interventions were significant for most of the studies in persons with Parkinson's (5/6 studies), dementia (4/5 studies), and older adults with balance impairments (3/3 studies). Remarkably, 2 studies in dual-task learning in persons with dementia[82] and older adults with balance impairments,[105] found between-group differences in favor of the single-task (control) intervention.

Study limitations

Our search strategy was carefully prepared by experts in the field of literature review and motor learning. Still, we might have missed studies because of limitations in the search strategy (eg, specifically included search terms) and the categorization of studies within databases. Publication bias might influence our findings; given the diversity of included studies, a funnel plot was not feasible.

As with any review article, our conclusions are subject to some common points of criticism concerning the standardized assessment of the studies' quality.[123] Despite careful preparation, we still experienced that the use of the RoB2 tool left room for interpretation and needed additional effort to increase the reliability of the assessment. However, missing information in the texts was not retrieved by contacting the authors. Information not reported is not necessarily information not retrieved, and therefore, the criteria list assesses the study's report, not necessarily the quality of the study.

In line with earlier reviews, we decided to include an additional criterion (ie, sample size justification) in our assessment of the included studies. An absence of sample size justification is not inherently problematic but increases uncertainties when evaluating effects.[120] Therefore, we excluded studies with a high risk of bias and without sample size justification from the descriptive analyses.

Future research

There are several considerations for researchers when conducting applied clinical motor learning research. Researchers should consider evaluating potential rehabilitation strategies not only within but also *across* populations.[124] Despite the anatomic and pathophysiological differences of target populations, these groups share many similarities, ranging from comparable cellular and neuro−physiological responses and recovery mechanisms to the effects of training in motor learning.

We also think that we should reconsider whether RCTs are the best fit for assessing complex training interventions. When conducting RCTs, researchers need to choose between internal validity (eg, the controlled context in laboratory settings) versus external validity reflecting daily practice (eg, more "uncontrolled" context with potential biases).[125,126] This may (partly) explain the overall moderate-to-high risk of bias and perhaps the absence of effects on some occasions. Hence, researchers should consider different research designs, eg, cohort studies or multiple baseline designs, which might be more suitable for pragmatic trials with complex interventions. To facilitate interpretations of study results by therapists, researchers should also consider using clinically relevant differences, for example, referring to minimally clinically important differences (MCIDs).[127] Likewise, to further increase the transferability to clinical practice, careful attention should be given to the description of the interventions. The Template for Intervention Description and Replication (TIDieR) can be used as a checklist and guide to ensure interventions are reported with sufficient detail.[128]

Conclusions

The results of this study provide an overview of the current state of evidence regarding 7 motor learning interventions in older neurologic and geriatric rehabilitation. The findings clearly show a skewed distribution of studies across motor learning interventions that have been researched within 5 target populations. The methodological shortcomings, for example, high risk of bias and lack of appropriate sample size justifications, make it difficult to draw firm conclusions regarding the effectiveness of motor learning strategies. Hence, this review cannot provide a strong basis for therapists to rely on in their decision-making. Based on observed trends, therapists may consider (to continue) using dual-task learning, observational learning and movement imagery. While waiting for future research, therapists may also consider the other motor learning strategies based on their own experiences and patients' preferences; the description of the interventions of the included studies could be an example of how to apply different strategies in daily practice within the different neurological and geriatric target populations.

Corresponding author

Li-Juan Jie, PhD, Nieuw Eyckholt 300, 6419 DJ Heerlen, The Netherlands. *E-mail address:* Li-Juan.Jie@zuyd.nl.

Disclosures

The authors declare no conflict of interest.

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Declaration of AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used the assistance of an AI language model provided by OpenAI, known as ChatGPT, to refine writing. After using this tool, the author(s) thoroughly reviewed and edited the content as needed and took full responsibility for the accuracy and integrity of the public.

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