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Extrinsic feedback for motor learning after stroke: What is the evidence?

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Abstract
Purpose.   There is little guidance on using extrinsic feedback to enhance motor learning after stroke. This narrative review synthesises research findings and identifies questions remaining to be answered.
Method.   A summary is given relating to the use of extrinsic feedback in healthy subjects. Then, research concerning content of feedback, feedback scheduling, and attentional focus is discussed in relation to patients with stroke.
Results.   Though research is scarce, preliminary key findings were as follows: Patients' balance performance can improve from receiving visual feedback about weight distribution during practice; auditory feedback of force production may improve performance of sit-to-stand; providing feedback on less than 100% of trials, and giving summary or average feedback may enhance learning; instructions or feedback inducing an external focus may be more effective than those with an internal focus. Further research is needed concerning the relative benefits of verbal, visual, video and kinematic feedback; reduced feedback frequencies and summary feedback schedules; feedback delays, error estimation, and self-controlled feedback; and attentional focus of feedback.
Conclusions.   Although there are some indications that feedback might enhance motor learning after stroke, there are many areas as yet not examined and there is clearly a need for considerable research in this area.

Keywords: *Motor learning, feedback, stroke, rehabilitation, physiotherapy*

Introduction

Feedback can enhance motor learning in healthy subjects. During training, the performer uses feedback to detect errors in performance by comparison of their movement to the expected goal, in order to improve the next attempt. Careful planning of content, scheduling and attentional focus induced by the feedback can enhance the effectiveness of training considerably. However, research examining these issues in stroke patients is scarce. This narrative review aims to synthesize the findings from current research on delivery of feedback to people with stroke, and identify the main questions that remain to be answered. Firstly, a short introduction will be given placing feedback in the context of motor learning and summarizing findings relating to the content and scheduling of feedback, as well as effects of attentional focus of feedback in the learning of healthy subjects.

Feedback can be classified as either 'intrinsic' or 'extrinsic'. Intrinsic feedback refers to a person's own sensory-perceptual information that is available as a result of movement being performed. Several sensory processes, including vision, proprioception, touch, pressure and audition, can mediate this information. Intrinsic feedback helps to formulate a person's internal representation of the movement goal he or she is trying to achieve. Extrinsic (or 'augmented') feedback, is feedback given in addition to intrinsic feedback, usually from an outside source, such as when a therapist comments on the quality of a stroke patient's attempt to stand from a chair. Extrinsic feedback has been categorized into either 'knowledge of results' (KR) or 'knowledge of performance' (KP). KR is 'externally presented information about the outcome of performing a skill or about achieving the goal of the performance' [1]. For example, a patient might be told that she was able to transfer 40% of body weight on to the hemiplegic leg, with bathroom

scales being used to measure the result. KP is "information about the movement characteristics that led to the performance outcome" [1]. For example, the therapist might tell the patient that the knee needs to be more extended in order to bear more weight on the hemiplegic leg.

Although it is clearly possible to learn motor tasks without extrinsic feedback, comparisons of KR and KP to no feedback at all show improved retention with feedback [2,3]. Feedback that provides information on errors in movement and how to correct them, can facilitate achievement of the movement goal by increasing the level of skill attained or by speeding up the learning process [1]. In the case of KP, this information may be more difficult to obtain intrinsically, as learners may not be so aware or so knowledgeable about their movements as the trainer, or may not be able to see the movements while actually performing the task.

Feedback is also important for sustaining motivation during learning. Extrinsic feedback can encourage persistence to master a skill in a physical education situation [4]. Skill acquisition is generally assumed to be facilitated more effectively if feedback contains information about errors rather than correct performance [1] (although see Chiviacowsky and Wulf [5]). Knowledge of correct performance can be helpful for motivation.

Feedback for learning in healthy subjects

As a preamble to the review of evidence on the use of feedback with people with stroke, the available information on content, scheduling and attentional focus of feedback with healthy subjects is summarized here.

Content

Prescriptive feedback (describing the errors *and* suggesting how to correct them [6]) was found to be more effective than descriptive feedback (just describing the errors) [7]. Increased precision of KR feedback can lead to better learning, though the research is inconsistent [8]. Thorpe [3] argues that to determine the content of feedback, the trainer needs to have analysed the movement task and identified all the essential components that produce skilled performance of the task. Feedback can then be given to the learner on these components. Feedback is commonly given verbally by the trainer, or visually (e.g., demonstration, video), or by manual assistance.

Verbal feedback can be an effective tool and erroneous verbal feedback can even override the person's own correct visual feedback in some situations. In a study by Beukers et al. [9], subjects practised an anticipation timing task. When given erroneous verbal feedback, it had the effect of overriding the person's own visual feedback, such that subjects adjusted their response to the incorrect verbal feedback. Also, verbal KR may be redundant when KR is inherent in a task. The same study demonstrated that there was no change in performance if correct verbal KR was given, compared to just receiving the visual feedback with each attempt.

Visual feedback is commonly given by demonstration by the trainer or by videotape. For more experienced learners, self-evaluation of videotaped performance works well as shown in a study of tennis players [2]. For less experienced learners, attention-directing cueing can be helpful, however [7,10]. A review of videotape studies by Rothstein and Arnold [10] concludes that videotape should be used over a number of weeks to enhance its effectiveness as a learning tool. Kinematic feedback has been found to be effective for learning of a bimanual coordination task [11], learning a golf shot [12] and increasing power output during a leg press exercise [13]. It frequently involves displaying results graphically to the learner, for example as joint angular displacement. Biofeedback provides information about physiological processes through the use of instrumentation [1].

Scheduling

Feedback can have negative effects if provided too frequently, such as the learner becoming dependent on it, or movement instability [8,14]. Studies have assessed various reduced feedback frequency manipulations, bandwidth, summary or average feedback manipulations, delayed feedback and error estimation procedures, as well as self-controlled feedback schedules.

Regarding reduced feedback frequency, a number of studies have shown that reducing the proportion of trials (e.g., 50%) for which feedback is presented during the practice phase can result in more effective learning than presenting feedback after every trial (100%) (e.g., Lai et al. [15], Weeks et al. [16], Winstein et al. [17], Wulf et al. [18], Wulf et al. [19]). That is, when performance is compared on retention or transfer tests (without or with feedback), groups that received less feedback during practice typically show enhanced learning. Learning benefits resulting from a reduced feedback frequency are may also be due to increased movement stability during practice [15,20].

In both summary feedback and average feedback conditions, performers are provided with feedback about a set of trials (e.g., 5) after this set has been completed. Whereas summary feedback involves

feedback about every trial in the set, average feedback refers to the average performance on that set of trials. Beneficial effects of summary feedback relative to single-trial feedback have been found in a number of studies [21–23]. The optimal number of trials summarized depends on the complexity of the task in relation to the performer's skill level, with shorter summary lengths being more effective for more difficult tasks or less experienced performers [21,23,24]. Results for average feedback are more equivocal [23,25,26].

Bandwidth feedback involves qualitative feedback when performance is within a certain range of error (e.g., 10%), indicating that performance is 'correct', and quantitative feedback when performance is outside the bandwidth (e.g., 70 ms too fast). Several studies have demonstrated benefits of bandwidth feedback relative to (quantitative) feedback provided after each trial [20,27,28]. The primary advantage of bandwidth feedback for learning seems to be that it promotes movement stability during practice. As a consequence, bandwidth feedback often results in more stable retention performance as well.

A feedback manipulation that has consistently been found to be detrimental to learning is feedback that is concurrently provided with the movement. Even though concurrent feedback has very strong performance-enhancing effects when it is present during practice, it typically results in clear performance decrements when it is withdrawn in retention or transfer tests, relative to feedback presented after the movement [29–32]. Also, presenting feedback instantaneously after the completion of the movement tends to create a strong dependency on it. One reason for the detrimental effects of concurrent and instantaneous feedback might be that they prevent spontaneous errors estimations, based on the processing of intrinsic feedback, that might occur during or after the movement. In contrast, delaying the feedback for a few seconds seems to promote those error estimations and has indeed been found to produce more effective learning [33]. Along the same lines, studies in which participants were specifically instructed to estimate their errors also provide evidence for the learning benefits of subjective movement evaluations [34,35].

Allowing the performer to decide when he or she wants to be provided feedback can be beneficial for learning [36–38]. It has been suggested that the perception of self-control enhances learning because it leads to a more active involvement of the learner in the learning process, promotes a deeper information processing [39–41], is more motivating [42,43] and makes performers take charge of their own learning process (e.g., Ferrari [44]).

Focus of attention

Numerous studies have shown that instructions that direct individuals' attention to the effects of their movements on the environment (e.g., implement, apparatus), thereby inducing a so-called 'external' focus of attention, are more effective for learning than instructions that direct attention to the movements themselves, or inducing an 'internal' focus (for a review, see Wulf & Prinz [45]). In a study by Shea and Wulf [46], a balance task (stabilometer) was used that required participants to keep the platform on which they were standing horizontal. Participants were presented with concurrent visual feedback, which consisted of the platform movements displayed on a computer screen. While one group was informed that the feedback represented movements of their feet (internal focus), the other group was told that the feedback represented lines attached to the platform in front of each of the performer's feet (external focus). The results showed that the group that interpreted the feedback as 'external' demonstrated more effective balance than the group that interpreted it as 'internal'. Interestingly, the beneficial effects of external focus feedback were not only seen during practice when the feedback was present, but also in retention when the feedback was withdrawn.

The benefits of adopting an external focus of attention have been explained with a more automatic type of movement control that is promoted when attention is directed to the movement effect. In contrast, when participants are asked to focus on their movements, they tend to actively intervene in the motor control processes, thereby disrupting automatic control processes ('constrained action hypothesis'). Support for this notion comes from studies showing shorter probe reaction times (indicating reduced attentional demands and a greater degree of automaticity), faster and more reflexive movement adjustments, and reduced electromyographic (EMG) activity for individuals adopting an external compared to an internal focus [47–49].

In contrast to the somewhat 'artificial' situation in the Shea and Wulf [46] study, physiotherapists typically provide patients with verbal feedback that refers to the aspect of the movement that needs the most improvement. This type of feedback was examined in a study by Wulf, McConnel, Gärtner, and Schwarz [50]. Specifically, they examined the effectiveness of feedback for the learning of motor skills (i.e., volleyball 'tennis' serve, lofted soccer kick), with feedback either being worded in a way that it induced an internal focus (e.g., "shift your weight from your back leg to your front leg") or external focus (e.g., "shift your weight toward

the target"). The results showed that learning was enhanced by the external relative to the internal focus feedback. Regarding frequency of feedback, in this study it was found that 100% external focus feedback was no different from 33% external focus feedback, and even tended to be more effective, in contrast to 100% internal focus feedback, which was detrimental to learning relative to 33% feedback [50]. This suggests that frequent feedback is not detrimental (and perhaps even beneficial) if it induces an external focus. Wulf et al. [50] argued that a high frequency of internal-focus feedback might be detrimental because it encourages learners to focus *too much* on their movements, while these effects should be attenuated under reduced feedback conditions. In contrast, feedback inducing an external focus presumably promotes a more automatic type of control, and frequent reminders do not appear to hinder the learning process.

Feedback for people after stroke

An important question for physiotherapists working in stroke rehabilitation is whether the research findings for healthy subjects apply to the person with stroke. This depends partly on whether people with stroke learn in the same way as those with intact nervous systems, and whether the tasks studied in the research are similar to those which the patient needs to learn. There is a small amount of research to answer the first consideration. After stroke, intrinsic feedback systems may be compromised, making it difficult for the person to determine what needs to be done to improve performance. Extrinsic feedback may thus be even more important to people with stroke. Studies have shown that patients with unilateral stroke are able to learn new motor skills [51,52], however implicit motor learning (learning perceptual-motor skills by physical practice without conscious awareness) may be impaired [53] particularly in patients with temporal lobe damage [54]. It has been suggested that provision of KR may allow explicit memory (knowledge of facts, events, and episodes) to assist motor learning in these patients [53,55]. Secondly, the skills that need to be learned by people with stroke include the performance of everyday tasks such as standing up, reaching to grasp an object, and walking. These seem similar to the kinds of sport skills that have been the focus of much of the research in healthy subjects. Although standing up may not seem as difficult as a sports skill such as serving in tennis, it may be perceived as difficult by the person who has suffered a stroke. Parts of tasks, e.g., extension of the wrist, are also practised, which also resemble some of tasks studied in healthy subjects (e.g., Beukers [9]). Although the processes by which people with stroke learn need to be further

elucidated with more research, there are some indications that findings from healthy subjects are relevant for this group.

Feedback content should be adjusted for the stage of learning of the subject. In the early stages of learning, information about the general framework and sequencing of components is beneficial, whereas in a later stage feedback can be more precise [56]. The role of the therapist is to provide feedback that is likely to assist learning in the most effective way. Feedback is probably delivered intuitively much of the time during stroke rehabilitation [57]. However, there is some evidence to guide the therapist so that feedback can be used in a more focused and deliberate way. In the next section, the evidence to date on use of extrinsic feedback in people with stroke is presented and critically appraised.

Review of evidence of use of feedback for learning after stroke

Content of feedback

Existing research on content of feedback for stroke patients focuses on assessing the effectiveness of instrumental feedback devices, rather than more fundamental issues such as contrasts between KR and KP, descriptive and prescriptive feedback, and different content of verbal feedback for different stages in the learning process. One exploratory study which included subjects with stroke, investigated the socio-affective characteristics of extrinsic feedback in physiotherapy [57]. Patient-physiotherapist interactions were videotaped and then subjected to systematic observation, in which behaviour was recorded into pre-determined categories of verbal and physical communications. This study found that verbal feedback was used extensively by physiotherapists and was used more frequently than visual feedback [57]. The verbal feedback was mainly motivational and reinforcing, with information feedback being used rarely. It was sometimes given concurrently with the patient's practice of the movement, which research in healthy subjects has indicated is counterproductive to learning [29 – 32]. This study does not allow assessment of the effect of different feedback on learning since it is exploratory – this should be a target of further research.

One study has specifically investigated the effect of KR after stroke [58]. Stroke subjects in this study were randomized into three groups and then underwent a three-week training programme of upper limb tasks. The first group received the training with KR, the second received the training without KR and the third group did not have the training. Although the training itself produced significant results compared to no training, when performance was measured at

the end of the 3 weeks, there was no substantial extra effect for KR. This could be because the tasks chosen had inherent information about the movement outcome, e.g., hitting targets with a stylus and placing objects on top of other objects, so that additional KR, which took the form of bar diagrams on a computer screen, did not enhance learning further. This is a similar result to the study by Beukers et al. [9] with healthy subjects, who found that extra verbal KR was redundant when outcome information is inherent in a task. Therefore, when outcome information is available, we can make the cautious interpretation that therapists may not need to give further informational KR. It may have a motivational role, however, and this needs to be investigated. Studies are also needed to elucidate whether KR will be useful in tasks where KR is not inherent, with stroke subjects. Therapists should also consider that setting tasks with inherent KR could be desirable, as it encourages self-control of performance, which has been found to enhance learning in healthy subjects [39–41]. Verbal feedback has been an element of treatment for stroke in two other randomised controlled trials, where positive effects were found for the entire intervention [59,60]. However, it was not possible to discern the particular contribution of the verbal feedback in these multi-faceted treatments.

Several studies have demonstrated that stroke patients can benefit from receiving visual feedback about weight distribution and weight shift activity. In a randomised controlled trial, Sackley and Lincoln [61] found significant improvements compared to a control group in stance symmetry and sway, motor function and activities of daily living after a 4-week training programme in which patients received feedback on a computer screen while attempting balance tasks on a balance platform. These changes were present 4 weeks after the intervention, but not at 12 weeks. In a similar study in which visual feedback was given about centre of gravity to more acute stroke patients [62], balance performance also improved but was not significantly different to a group receiving the same amount of balance training via the verbal and tactile cues more typically used in physiotherapy. Altschuler et al. [63] compared training of symmetric arm movements in a mirror to symmetric arm movements using a plastic sheet in a randomised crossover design. Subjective comments by the patients and ratings of improvement by researchers based on videotapes of 'cardinal movements of the upper limb' indicated that it might be beneficial for some patients. The lack of reliable outcome measures and adequate statistical analysis, however, means that this finding should be regarded with caution. Visual feedback was concurrently and continuously displayed to the learner in the above

studies, which could be detrimental to learning, even though it improves performance, because of reduced opportunity for the patient to use their own intrinsic feedback, leading to a potential dependency on extrinsic feedback [64]. In future studies comparing different content of feedback, it would be useful if the scheduling of feedback reflected the recommendations from more recent research, so that it was slightly delayed and given with reduced frequency.

Auditory feedback of force production was also shown to improve performance of the sit-to-stand movement by Enghardt et al. [65]. In a randomized controlled trial, the experimental group received ground reaction force feedback via auditory input, whereas the control group received no feedback about ground reaction force. When measured at the end of a 5-week programme of daily practice of sit-to-stand, the experimental group achieved significantly greater symmetry in body-weight distribution than the control group. Portable weight distribution auditory feedback devices have been employed also (e.g., Batavia et al. [66]). One study evaluated the effect of such a device on performance of sit-to-stand [67]. A small group of patients receiving auditory feedback during practice of sit-to-stand for a period of 3 weeks were compared to a control group who underwent the practice without the feedback. The results were equivocal although there was a tendency for the feedback group to increase force production through the affected lower limb more than control subjects. Dursun et al. [68] also demonstrated positive effects for an angular biofeedback device for sitting balance. The device was positioned on the midline of the back, and gave information about tilting from the erect position with feedback given both by visual and auditory signals. Balance performance was significantly better on some of the measures used, compared to the control group, after 10 days of treatment, but the difference was not maintained at discharge. The study was not randomized and so it is not clear whether biased patient selection contributed to the results.

Effects of kinematic feedback in stroke rehabilitation have received little attention in the literature. One quasi-randomised study has examined the effect of kinematic feedback via electrogoniometry for the purpose of limiting knee hyperextension [69]. Peak knee hyperextension was improved more than the control group after a 4-week training period. A positive aspect of this study is that frequency of feedback information from research in healthy subjects was applied so that patients only received feedback if the knee was extended past the 0 degree position (bandwidth feedback). It has been argued that another group receiving non-bandwidth feedback could have been included to assess the effect of bandwidth [64]. This is a good point as it is not clear

yet whether the general finding that reduced frequency of feedback is better for retention in healthy subjects, applies to subjects with stroke. It is particularly relevant, as the electrogoniometry feedback induces an internal focus of attention (see section on healthy subjects). Another admirable aspect of the design was that results were based on a retention test 4 weeks after cessation of the training, unlike some of the studies with people with stroke, which tested the change in performance as a result of the feedback intervention. An interesting case study showed improvement in gait parameters when regularly shown a graph of performance [70]. The patient was covertly monitored by staff who observed the size of her base of support and step length, and this information was fed back to the patient daily on a graph showing the number of times the correct step length or base of support was observed. Another common form of biofeedback, EMG, will not be discussed here, as it has been the subject of several earlier papers.

There are other instrumental forms of feedback under development for stroke rehabilitation, such as virtual reality-augmented training. For example, the patient can wear different types of gloves containing infrared sensors and force transducers while attempting upper limb movements – one for monitoring amplitude, speed and fractionation of movement, the other, a force feedback glove, monitoring strength of finger flexion and extension movements [71,72]. Online visual, auditory and force feedback was provided via a personal computer. Exercises were in the form of imaginative computer games with graphics feedback and goals were set according to ability. One and a half hours of virtual reality training plus practice of fine motor tasks, spread over a period of 3.5 h per day for 2 weeks, was found to have good effects. A similar training programme which used video-game like tasks had good effects for training pronation, supination, and wrist movements [73]. A type of web-based telerehabilitation has been described [74], which aims to provide low cost, intensive, repetitive practice of functional movements via input devices such as a force feedback joystick and traditional mechanical mice, or gyroscopic or force feedback mice. Randomised controlled trials are yet to be conducted to assess the effectiveness of these methods.

Scheduling of feedback

Relatively few studies have examined feedback scheduling effects in stroke patients. Even though no studies seem to have looked at error estimation and self-controlled feedback effects, some studies have examined the effects of feedback frequency, summary, average and summary feedback, as well as feedback delay (for a review, see Ezekiel et al. [64]).

Reduced feedback frequency. Winstein, Merians and Sullivan [52] used a task, in which participants had to produce a spatially and temporally defined arm movement pattern (lever positioning), to compare feedback frequency effects (100% vs. 67%) in healthy, older adults and a group of individuals who were an average of 2 years post-stroke. In a retention test, the reduced feedback frequency during practice resulted in increased consistency for healthy and stroke patients, even though movement accuracy did not differ from the respective 100% feedback conditions. In a study using a linear arm positioning task [75], different groups of individuals with brain injury and aged-matched controls practiced under 33%, 67%, and 100% feedback conditions. There were no significant differences between feedback frequency groups in retention test, although both reduced frequency groups tended to be more accurate than the 100% condition. Finally, Saladin, Baghdady, and Nichols [76] report that stroke patients practicing an isometric force modulation task benefited from a reduced feedback frequency (50%) compared to 100% feedback, as demonstrated in a retention test after 24 h. Thus, even though there is no compelling evidence that reducing the feedback frequency is beneficial for stroke patients, at the very least, the findings suggest that it is not harmful.

Summary and average feedback. A study by Croce, Horvat and Roswal [77], using a coincidence timing task, provided some evidence for the effectiveness of summary and average feedback in individuals with traumatic brain injury. Compared to groups that received no feedback (control) or feedback after every trial, both summary and average feedback groups performed more effectively on an immediate retention test, and the summary feedback group was most accurate on a 24-h retention test.

Overall, the findings regarding feedback scheduling effects in stroke patients are somewhat equivocal. Clearly, more studies are needed, including ones that use more complex and functional tasks (see Ezekiel et al. [64]). Also, one factor that needs to be considered in this context is the relative task difficulty. Wulf and Shea [50,78,79] have argued that, whereas the learning of simple tasks might be enhanced by making practice more difficult or challenging for the learner (e.g., by reducing the feedback frequency), the learning of relatively complex skills might not benefit from, and might even be degraded by increasing the demands imposed on the learner. Clearly, a relatively simple task for a healthy subject could be difficult for a stroke patient. Thus, a reduced feedback frequency might not necessarily have the same

advantages for stroke patients as it would have for healthy subjects. Furthermore, given the types of tasks that individuals suffering from a stroke learn in physiotherapy setting, feedback might not be as prescriptive as it often is in many simple tasks practiced in laboratory settings. Real-life tasks often require the coordination of different components to produce skilled performance. To improve performance, the learner has to rely on many sources of intrinsic feedback, and the likelihood of patient becoming dependent on the extrinsic feedback and completely neglecting the processing of intrinsic feedback might be reduced.

Focus of attention

While there do not appear to be studies that specifically examined the effectiveness of external versus internal focus feedback in stroke patients, Fasoli, Trombly, Tickle-Degnen and Verfaellie [80] investigated the effects of external vs. internal focus instructions in patients who had a cerebrovascular accident (CVA). Specifically, they used patients and non-impaired control participants to examine how the type of focus affected performance of daily-life tasks. Fasoli and colleagues found that both groups performed various tasks (e.g., taking an apple off a shelf and putting it into a basket; moving an empty coffee mug from a table onto a saucer) more effectively if given external rather than internal focus instructions. Movement times were shorter and peak velocities were greater on all tasks, suggesting that these patients as well as control participants pre-planned their movements to a greater extent and used more automatic control processes when they focused externally.

The learning advantages of external focus feedback shown for healthy participants may be of benefit to people with stroke, particularly where attention is directed to the movement effect, rather to the movements themselves. This appears to be a fruitful direction for future research. Future studies should also use learning paradigms, including the use of retention or transfer tests without feedback, to examine the permanency of the attentional focus effects, if any. If benefits of practicing a skill under external focus conditions were found in situations in which subjects are not reminded to adopt, or are even prevented from adopting (e.g., Totsika & Wulf [81]), a specific attentional focus, this could have important implications for physiotherapy settings.

Key findings for stroke therapy:

Because of the small number of studies available, the following summary comments should be regarded as preliminary:

- Additional verbal KR from the therapist may be redundant when outcome information is inherent in the task.
- Patients' balance performance can improve from receiving visual feedback about weight distribution during practice.
- Auditory feedback of force production may improve performance of the sit-to-stand movement.
- Providing patients with feedback on less than 100% of the trials may enhance learning.
- Giving patients summary or average feedback might benefit the learning process.
- Instructions or feedback inducing an external focus may be more effective than those with an internal focus to improve performance of tasks after stroke.

Questions that need to be answered:

- How do physiotherapists deliver feedback in current practice (in detail)?
- Do patients with stroke benefit more from prescriptive information on errors than on correct performance?
- Do patients with stroke benefit more from KR or KP?
- Is their learning enhanced by video and kinematic feedback?
- Do patients with stroke benefit the same from feedback after every trial or a reduced feedback frequency?
- Does a reduced feedback frequency improve retention after stroke?
- Is concurrent feedback, feedback immediately after performance, or delayed feedback more effective for retention?
- Is feedback with an external focus more beneficial for learning after stroke than feedback with an internal focus?
- Do patients with stroke benefit from frequent feedback when feedback induced an external focus?
- How do feedback type and frequency interact with the stage of learning?

Conclusion

Some of the research presented indicates that feedback can enhance motor learning after stroke. So there is some justification for using it in stroke rehabilitation. However, there are many areas as yet not examined and there is clearly a need for considerable research in this area. There is a dearth of studies on how variables, which have been shown to enhance learning in young, non-impaired populations, affect the re-learning of motor skills in

stroke patients. These include the relative benefits of verbal, visual, video and kinematic feedback, reduced feedback frequencies and summary feedback schedules, as well as feedback delays, error estimation, and self-controlled feedback. Another fruitful direction for future research might be a further examination of the effects of feedback inducing an external versus internal focus of attention, and how external focus feedback, if shown to be beneficial, can be implemented in physiotherapy settings. Methodologically, studies examining the effect of feedback on motor learning of patients with stroke have not always distinguished between learning and performance. The main focus has been whether performance is improved during training, or immediately after the training. Yet, as the goal of any intervention is improved performance in the long term (i.e., learning), retention or transfer tests conducted some time after the end of training are necessary.

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