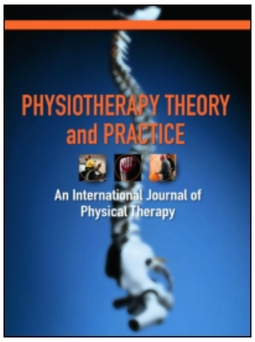

Physiotherapy Theory and Practice
An International Journal of Physical Therapy

ISSN: 0959-3985 (Print) 1532-5040 (Online) Journal homepage: http://www.tandfonline.com/loi/iptp20

Application of motor learning in neurorehabilitation: a framework for health-care professionals

Melanie Kleynen, Anna Beurskens, Huub Olijve, Jip Kamphuis & Susy Braun

PHYSIOTHERAPY THEORY AND PRACTICE
https://doi.org/10.1080/09593985.2018.1483987

Application of motor learning in neurorehabilitation: a framework for health-care professionals

Melanie Kleynen, PT, PhD [a,b], Anna Beurskens, PT, PhD[b,c], Huub Olijve, PT[d], Jip Kamphuis, PT, MSc[e], and Susy Braun, PT, PhD[a,b]

[a]Research Centre for Nutrition, Lifestyle and Exercise, Faculty of Health, Zuyd University of Applied Sciences, Heerlen, Netherlands; [b]CAPHRI, Care and Public Health Research Institute, Faculty of Health, Medicine and Life Sciences, Maastricht University, Maastricht, Netherlands; [c]Research Centre for Autonomy and Participation of People with a Chronic Illness, Faculty of Health, Zuyd University of Applied Sciences, Heerlen, Netherlands; [d]Department of Brain Injury, Adelante Rehabilitation Centre, Hoensbroek, Netherlands; [e]Department of Rehabilitation, Amsterdam UMC University Medical Centre, Amsterdam, Netherlands

ABSTRACT

Learning motor skills is an essential part of most rehabilitation processes. Facilitating and supporting motor learning is particularly challenging in neurological rehabilitation: patients who suffer from neurological diseases experience both physical limitations and difficulties of cognition and communication that affect and/or complicate the motor learning process. Therapists (e.g. physiotherapists and occupational therapists) who work in neurorehabilitation are therefore continuously searching for the best way to facilitate patients during these intensive learning processes. To support therapists in the application of motor learning, a framework was developed, integrating knowledge from the literature and the opinions and experiences of international experts. This article presents the framework, illustrated by cases from daily practice. The framework may assist therapists working in neurorehabilitation in making choices, implementing motor learning in routine practice, and supporting communication of knowledge and experiences about motor learning with colleagues and students. The article discusses the framework and offers suggestions and conditions given for its use in daily practice.

ARTICLE HISTORY
Received 1 June 2017
Revised 18 December 2017
Accepted 30 March 2018

KEYWORDS
motor learning; framework; neurological rehabilitation

Introduction

Learning motor skills is an essential part of most rehabilitation trajectories. Motor learning has been described as a "*set of the processes associated with practice or experience leading to a relatively permanent change in the capability for skilled behaviour*" (Schmidt and Lee, 2011). People in rehabilitation often need to learn new skills like using a wheelchair or a walking aid, as well as "old" skills they used to possess, such as getting up from a chair, walking, or eating with a knife and fork. Therapists (e.g. physiotherapists and occupational therapists) who work in rehabilitation are therefore continuously searching for the best way to support patients during these intensive learning processes. The support for learning is particularly challenging in neurological rehabilitation as people suffering from neurological diseases often experience difficulties of cognition and communication, in addition to physical limitations (Rasquin, Verhey Lousberg, and Lodder, 2005; Rasquin et al., 2002; Rasquin, Welter, and van Heugten, 2013). These cognitive and communicative difficulties may affect and/or complicate the motor learning process.

During the twentieth century, allied health treatment of motor problems of people who have a neurological disorder was mainly based on several treatment concepts such as Bobath (Bobath, 1990; Davies, 1985), proprioceptive neuromuscular facilitation (Knott and Voss, 1986), and the Brunnström concept (Brunnström, 1992). In recent decades, however, evidence suggests that strictly treating patients according to only one of these concepts is not advisable (Kollen et al., 2009; Pollock et al., 2014). This is why a more eclectic approach is currently recommended, in which task specificity, intensity, and dose are important basic principles (Kollen et al., 2009; Langhorne, Bernhardt, and Kwakkel, 2011). These principles may seem simple, but they have been interpreted and implemented in many different ways (Depaul et al., 2015). This could explain why experienced therapists use a large diversity of options when applying motor learning and also often switch between these options (Kleynen et al., 2017). They base their choice to apply a particular form of motor learning on many factors, such as the patient's characteristics (e.g. physical, cognitive, and emotional consequences of the disorder, location of the brain

CONTACT Melanie Kleynen, PT, PhD melanie.kleynen@zuyd.nl Research Centre for Nutrition, Lifestyle and Exercise, Faculty of Health, Zuyd University of Applied Sciences, Heerlen, Netherlands
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/iptp.

damage, and age of the patient), the patient's expressed care needs, and the agreements made within a multidisciplinary team (Kleynen et al., 2017). The diversity of motor learning options and the large variety of underlying factors on which choices are based makes them complex, but this seems inevitable given the heterogeneity of the target group (Pollock, Baer, Langhorne, and Pomeroy, 2007). However, all these various options and factors make it difficult for less experienced therapists and students to achieve a comprehensive view regarding the application of motor learning in practice.

Furthermore, the number of scientific studies into the best way to apply motor learning has increased exponentially in recent years (Fisher, Morton, and Lang, 2014). However, these studies are mostly based on laboratory research investigating constructed tasks under standardized circumstances (Kal et al., 2016). Although the number of studies is increasing, there is still a lack of randomized controlled trials (RCTs) comparing motor learning interventions in clinically relevant tasks (Kal et al., 2016) and almost no evidence regarding which motor learning strategy works best for which patient and under which conditions. In the absence of evidence in the field of neurological rehabilitation, therapists might approach research in other target population where at least on certain aspects more evidence can be found (e.g. in sport psychology, surgery, children, and orthopedics) (Benjaminse, Welling, Otten, and Gokeler, 2015; Capio et al., 2013; Masters, Lo, Maxwell, and Patil, 2008).

Often, these research fields use different terms to describe and compare interventions and different models to explain motor learning (Kleynen et al., 2013a). This lack of a uniform terminology impedes the efforts to translate the scientific knowledge into practice, as well as the exchange of knowledge between therapists and students about motor learning.

In practice, therapists working in rehabilitation need to decide how to apply motor learning for every patient and diversity of different task, besides the uncertainty on effects and terminology. They also need to clearly communicate and document their decision and argumentations in treatment plans. In order to gain more insight into the use of terminology and define and categorize the various terms (taxonomy), a study using a Delphi technique among international experts of motor learning was initiated (Kleynen et al., 2014a). In addition, participating experts who had practical experience were asked to describe the practical application of several motor learning strategies[1] (Kleynen et al., 2015). As part of this Delphi study, a framework for the application of motor learning was proposed.

The framework provides an overview of options and an indication of how these options might be related (in theory) and used (in practice). We would like to emphasize that this framework is mainly based on theoretical, plausible assumptions, opinions, and experiences of the Delphi expert group (researchers, therapist, and lectures, n = 49). It is therefore important that potential users of this framework realize that it is a starting point and still under development. None of the options presented in the framework has yet proven to be in general superior. However, in this phase the framework can be used to provide an overview of the possible options, together with their assumed underlying working mechanism, and therefore guide clinical reasoning and purposeful decision-making. The purpose of this article is to present the framework, illustrated by cases from practice. The article first presents a brief description of the framework (a more detailed description of all parts of the framework is available in the Appendices). It then discusses the framework and offers suggestions and conditions for its implementation in daily practice. Please see previously published previously published articles for a description of the development and background of the framework (Kleynen et al., 2013a, 2014a, 2015).

Description of the framework

The framework (Figure 1) consists of three different "layers." The basis for the framework is the distinction between implicit and explicit forms of motor learning. This distinction is visualized in the upper layer of the outline. In the second layer, several learning strategies are presented. The bottom, most practical layer, consists of three elements: (1) organization, (2) feedback, and (3) instructions. These elements are used in the practical application of the learning strategies, tailored to the individual patients. Factors that are important to consider regarding a specific use of motor learning are shown at the bottom of the framework: the patient's abilities, the type of motor task, and the learning stage. The layers and components of the framework are discussed in more detail below.

Forms of learning: implicit and explicit

Implicit and explicit forms of motor learning form the conceptual basis of the framework. This distinction is widely used in the literature about learning in general (Reber, 1967), motor learning by people without health problems (e.g. athletes and children) (Masters, 1992), and rehabilitation (Beek and Roerdink, 2014; Steenbergen et al., 2010).

[1]The term "(motor) learning strategy" is used in this article with the following definition: a learning strategy includes motor learning options that share a common background/theory and therefore also have comparable practical characteristics.

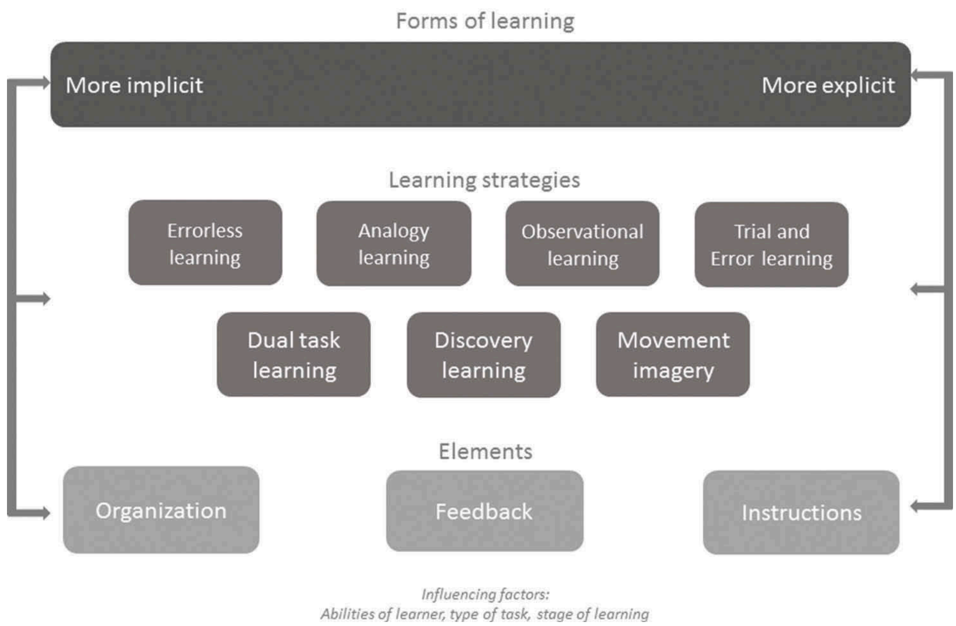

Figure 1. A framework for the application of motor learning (basis).

In explicit learning, also referred to as conscious learning, the patient acquires verbal knowledge (i.e. rules and facts) about a movement, and there is a cognitive stage in which the patient is aware of what he or she is learning. The learner has to collect, process, remember, and translate the rules and facts that have been gathered during the learning process into a (motor) task (Masters, 1992; Masters and Poolton, 2012). The working memory is essential for explicit learning as this is where rules and facts are processed (Berry and Broadbent, 1998). The therapist can provide the patient with these rules. A patient can also discover rules and facts by making mistakes and analyzing and correcting these mistakes through "trial and error" learning.

In implicit learning, patients might be aware that they are learning, but they should not be aware of the details of the learning process itself. The learners receive little, if any, verbal information, so they have to process fewer rules and facts about the motor task. This implies that the working memory does not likely have to process this information (Masters and Poolton, 2012; Maxwell, Masters, and Eves, 2003). When implicit learning is put into practice, therapists can use sensitization, habituation, association, and automatism to teach their learners (Shumway-Cook and Woollacott, 2006). An example is the unconscious adjustment of the gait pattern when walking on different surfaces. Changing the surroundings (i.e. different obstacles or surface) can influence the learners' motor behavior, without any explanation being given. The learners are subconsciously "seduced" to adjust the movement.

The division of learning into explicit and implicit shows a kind of continuum, rather than a distinct dichotomy (Kleynen et al., 2014a; Reber 1993). This means that learning processes can be more implicit or more explicit (e.g. depending on the numbers of rules and facts), and that these two modes of learning may also be combined.

Learning strategies

The second layer of the framework includes seven learning strategies, which have all been described in the general literature and in studies of the use of motor learning. This selection of strategies is based on the professional opinions of experts (i.e. represent the most commonly know ones) (Kleynen et al., 2015). Based on these professional opinions, the selected learning strategies have been classified into strategies that are likely to promote more implicit and those likely promoting more explicit forms of learning. A learning strategy includes motor learning options that share a common background/theory and therefore also have comparable practical characteristics. This does not mean that there is no variation in the way each strategy is applied. For example, the common characteristic of the strategy of "observational learning" is that the patient first observes a movement and then tries to copy it. This strategy can be realized by observing a therapist, another patient, or a video. Observational learning can become more explicit when the therapist gives verbal explanations before or during the observation. This learning strategy can also become more implicit when the explanation is limited to a minimum or when the therapist only asks the learner to just "copy" the movement. An overview and a description of the learning strategies is provided in Appendix 1.

Elements

A therapist needs several elements to put motor learning into practice. Within the framework, these elements are clustered into three categories: (1) instructions, (2) feedback, and (3) the organization of the learning environment and the task to be learned. These elements were chosen based on the results of the Delphi method and decision-making of expert physiotherapists (Kleynen et al., 2015, 2017). The use of learning strategies or a specific form of learning involves a combination of these elements. For instance, the learning strategy of "analogy learning" requires the use of a specific instruction. The learning strategy of "errorless learning" can be applied by organizing the learning environment to ensure that errors are less likely to occur. The strategy of "trial-and-error learning" can be supported by giving feedback on errors that have been made. An overview of the three elements with an explanation and examples is included in Appendix 2.

Relation between forms of learning, strategy, and elements

The framework visually distinguishes the three levels described above: (1) forms of learning, (2) strategy, and (3) elements. It is important to mention that the organization of the levels does not indicate a hierarchy between the levels. The levels are interrelated, which is indicated by the arrows. In practice, this means that a choice for a certain motor learning option can be on any level and does not need to contain all three levels. Therapists may choose to use a more explicit approach (i.e. form of learning) and apply this by using a combination of verbal instructions and feedback (i.e. elements), without particularly choosing a learning strategy. They may also choose to use analogy learning (i.e. learning strategy) that needs analogy instructions (i.e. element) and will most likely promote implicit learning (i.e. form of learning).

Factors that may influence the choices within motor learning

Eventually, the therapist needs to decide along with the patient which combination of motor learning options will be used. A great amount of factors might influence and direct this decision (Kleynen et al., 2017). These factors can be clustered in three categories: (1) abilities of the learner, (2) type of task, and (3) current learning stage (Kleynen et al., 2015). The use of motor learning has to be tailored to the learner, which implies that the therapist needs to take the characteristics of the learner, in this case, the patient into account (e.g. the pathophysiology of the condition, comorbidities, and their age). It is also important within the selection process to consider the characteristics of the task that has to be learned and the circumstances under which the task has to be carried out in daily life (e.g. cyclic open tasks like walking might ask for a different approach than tasks that can be divided into smaller steps like making coffee). The patient's current learning stage (e.g. beginning of the learning process or later phase in which movements will be more sophisticated) can also influence the choices. An explanation of the factors is presented in Appendix 3.

Based on the current state of literature, it is not possible to describe specifically how the selected factors might influence the decision-making. The information presented in Appendix 3 might help therapists to get an overview of the factors that can be considered and probably measured/investigated in order to find an optimal motor learning approach.

The use of the framework in real-world examples (cases)

Below, authentic cases are presented to illustrate how a therapist can use the framework to support the choice of a specific form of motor learning. A common basic assumption in these examples is that the therapist has studied the patient's medical records and has carried out the usual assessment according to professional guidelines. The interpretation of the measurement outcomes from the assessment and the observations made during the performance of these tests reveals first insights into the patient's abilities regarding learning (e.g. can the patient follow the instructions?). The therapist thus gains information about the factors that may influence the choice of a specific form of motor learning (Appendix 3). The framework is then used to decide on which motor learning options are used and to develop a patient-tailored plan.

Patient A

Table 1 provides the details of the first case. This is followed by a description of a possible implementation of motor learning, together with the underlying argumentation. Patient A has set herself the goal of transferring safely and independently from the wheelchair to the bed and the toilet, first at the rehabilitation center and then later at home within 4 weeks. The therapist chooses the learning strategy of errorless learning based on the details in Table 1, the observations made during the assessments, and the first attempts to practice the transfer. These are his arguments:

Table 1: An overview of the problems faced by patient A and relevant factors, based on the International Classification of Functioning, Disability and Health (ICF)

Disease	Ischemic stroke in the right hemisphere two weeks ago
Functions	- Poor balance (Trunk Control: 37/100; Berg Balance: 5/56) - Left arm: flaccid paresis, no selective motor control (Motricity Index: 0/100) - Left leg; Some strength in knee and hip (Motricity Index: 28/100) - Tone in leg: increased (Modified Asworth Scale leg: flexion: 1 extension: 2) - Global sensory assessment: patient feels tactile stimuli on her left side when she concentrates - Memory seems fine - Difficulty keeping up attention (patient easily gets distracted) - Reduced perception of her left side - Reduced awareness of illness- Patient is not well able to grasp that there is a higher risk of falling
Activities	Patient is able to transfer from wheelchair to bed with physical help of two persons in her room at the rehabilitation centre
Participation	Patient is not capable of taking care of her children or carrying out domestic tasks
Personal factors	- 49 years old, female - Acts quickly and impulsively - Restless - Emotional - Difficulty with planning and organising a complex (motor) task - Limited experience of making a transfer (initial stage of learning)
External factors	- Married, three children - Pets - Current situation: adjustable height bed in a single-occupant room at the rehabilitation centre. - Home environment: double bed, not adjustable in height

errorless learning can be very motivating for the patient because it means she is not confronted with "errors." This approach can be favorable for a patient who easily becomes emotional. A structured learning environment can also be beneficial for a patient who has difficulties planning and organizing. The therapist thinks that the order in which actions are carried out is especially important for this complex task. Given the patient's balance problems, he expects that structuring the task will provide more safety. Characteristics of errorless learning include repetition and a gradual increase in the degree of difficulty. This can also be favorable for patients who act restlessly and impulsively. His decision to use errorless learning also fits in with the early stage of learning. The patient has just been admitted to rehabilitation and started to practice the motor skill, so she does not yet have a lot of experience and has made few errors yet. This implies that she had probably not yet built up explicit knowledge about the motor skill. Based on these arguments, the therapist chooses the following elements to specify the application of errorless learning in practice (Figure 2).

Patient A has been admitted to a rehabilitation center after an ischemic stroke in the left hemisphere 2 weeks ago. She is attending an intensive multidisciplinary program. At the moment, her main goal is to function independently in her home environment.

At the moment, patient A uses a wheelchair. She sometimes needs help using her wheelchair due to reduced perception of her left side.

She also needs a great deal of help from the nursing staff (two persons) in transferring to the bed and the toilet. Together with her physiotherapist, the patient

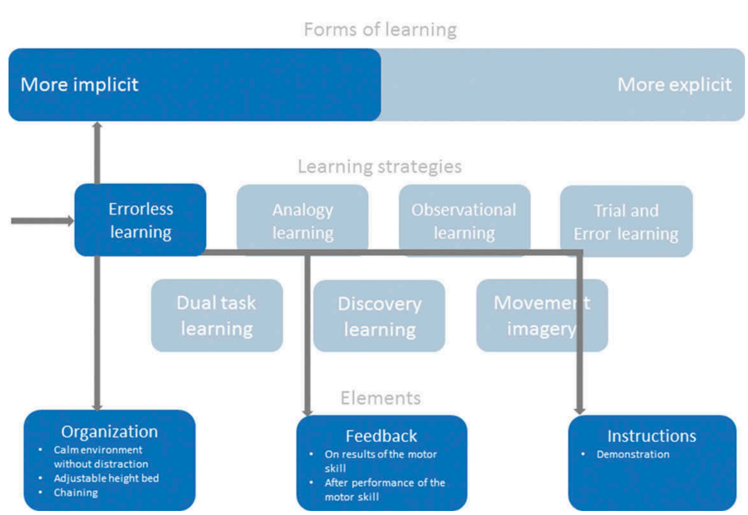

Figure 2. Choices within framework for patient A (start rehabilitation).

has set the following therapy goal: within 4 weeks, she wants to be able to transfer safely and independently from the wheelchair to the bed and the toilet (first in the rehabilitation center and then later at home).

Already during the first therapy sessions the physiotherapist notices that the patient is struggling to carry out the various steps of this motor skill in the correct order. Patient A is, for instance, skipping steps. As her balance is poor (Berg Balance Scale: 5/56) and she also easily gets distracted, her performance of the transfer is unsafe.

Patient A easily becomes emotional when her therapist points out that she is not performing it safely or even when she notices this herself.

The therapist wants to find an approach that would fit the patient's capabilities as soon as possible.

Organization

The therapist chooses a calm learning environment with few distracting factors using a bed with adjustable height. The therapist can structure the learning process according to the principle of forward/backward chaining. This means that the patient realizes the first step of the motor task herself (e.g. parking the wheelchair correctly alongside bed). The therapist supports the patient during the subsequent steps (e.g. through manual assistance and demonstrations [more implicit]). Once the patient has mastered the first step independently and safely, she can try to carry out the second step. In this way, the patient is actively involved in the learning process and the therapist can still make sure that the number of errors is limited. In backward chaining, the procedure is followed inversely: the therapist assists in the realization of the first steps and the patient carries out the last step independently. Chaining is a way to structure the learning process and to prevent errors. The principle of chaining is suitable for this type of task because transferring from wheelchair to bed can be clearly divided into sub-steps and has a specific final goal (closed and discrete task).

Feedback

The therapist limits the feedback to information regarding the result of the movement (knowledge of results) (e.g. "This is the correct position, well done"). He argues that given the early stage of learning and the patient's goal, the training should focus on security and independence and not on efficiency and the optimization of the motor performance for which knowledge of performance could be used. The therapist only provides feedback after the patient has completed the motor task in order to not unnecessarily distract her. He will only intervene if the patient puts herself in an unsafe situation. He will then interrupt the performance and ask her to start over (preventing errors).

Instruction

The therapist limits his verbal instructions because the patient is easily distracted. Instead he demonstrates the sub-steps and provides brief instructions with an external attention focus (e.g. "Watch closely what I'm doing and then try to copy me"). This approach is likely to promote a more implicit form of motor learning. He demonstrates only sub-steps of the movement not the entire transfer because the patient is easily distracted and has difficulty observing her performance of the task as a whole.

Patient A, after 6 weeks. Patient A has now been in rehabilitation for 6 weeks. She can now transfer independently in familiar and calm environments. Since the patient is almost ready to be discharged home, her goal has changed to being able to transfer independently and safely in her own home environment. The therapist and the patient have recently been to the patient's home environment to practice the transfers. The patient was able to safely transfer in different situations (e.g. bedroom and living room), except when she was distracted. The patient has a lively home environment. She has three children (11, 15, and 18 years old) and two cats who cause considerable distraction. As result of her stroke, she is also more easily distracted.

After talking with the psychologist, the therapist suspects that the patient will eventually learn to focus better, so that she will be able to continue to perform the primary task (in this case, the transfer) even when she gets distracted. Since the therapist cannot frequently practice with the patient in her home environment that would have been preferable given the benefits of context specificity (Langhorne, Bernhardt, and Kwakkel, 2011; Legg and Langhorne, 2004), he chooses to continue therapy in a lively environment with a lot of distractions. He ensures that there is a build-up in the level of liveliness of the environment. For example, he begins by practicing the transfers in a busier practice room and then practices in the hallway where people are passing by. To make sure that the patient will also be able to perform the transfer safely in the future, the therapist could take this a step further and cause distractions by adding a second task (i.e. dual-task learning). This can be done, for example, by asking the patient a question while she is performing the transfer. In this case, the therapist makes the deliberate decision only to choose a combination of elements. The use of these elements will most likely not lead to increase in verbal knowledge of the task and might therefore most likely promote a more implicit motor learning (Figure 3).

Patient B

Patient B has set himself the goal of putting on his sling independently. It is important that this goal is achieved

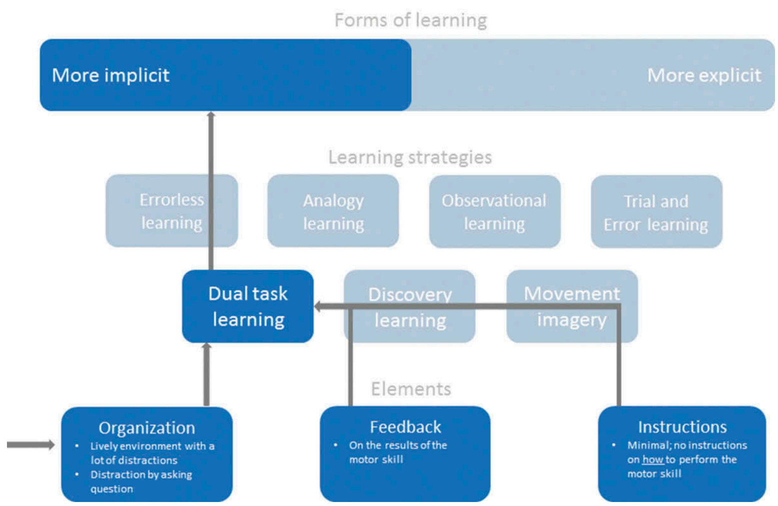

Figure 3. Choices within framework for patient A (after 6 weeks).

Table 2: An overview of the problems faced by patient B and important factors based on the International Classification of Functioning, Disability and Health (ICF).

Disease	Focal infarction in the left hemisphere six weeks ago
Functions	- Patient has enough balance to walk independently (Berg Balance Scale: 52/56)
	- Flaccid paresis right arm, no motion possible in right arm (Motricity Index upper limb: 0/100)
	- Concentration, attention and memory seem fine.
	- Patient suffers from aphasia; He can follow verbal instructions well.
	- He can adequately indicate 'yes' and 'no'
	Severe shoulder pain
Activities	The patient walks independently around the house with a cane (FAC 4), he needs help with ADL tasks
Participation	The patient is currently not able to function in his home environment because he needs help and support with ADL and IADL tasks
Personal factors	- 68 years old, male
	- single
	- Has never performed any sports
	- Appears clumsy sometimes
	- Patient is right-handed
External factors	Sling to support shoulder

FAC: Functional Ambulation Category; ADL: Activity of Daily Living; IADL: Instrumental: Activity of Daily Living

soon, as not being able to put on the sling limits his independent mobility. Therefore, he strives to achieve this goal within the next week. An overview of the details of patient B is presented in Table 2.

The therapist chooses to use a more explicit approach. This is her argument; it is important that the patient learns the new task quickly. Explicit motor learning generally seems to progress faster (Masters and Poolton, 2012). Further, from earlier sessions the therapist knows the patient can remember and carry out a limited number of verbal instructions. An advantage of implicit learning is that implicitly learned tasks seem more stable under dual-task conditions and despite fatigue (Masters and Poolton, 2012). However, the patient is not expected to put on the sling under dual-task condition or when fatigued.

The therapist does not choose a specific learning strategy presented in the framework. She rather combines the elements of organization, instructions, and feedback in order to create an optimal, tailored approach (Figure 4).

Patient B was admitted to the same rehabilitation center as patient A after suffering from a focal infarction in the left hemisphere 6 weeks ago. His main goal is to function independently in his home environment. He walks independently around the house with a cane. At the moment, the patient experiences severe shoulder pain. As a consequence, he has difficulty sleeping, washing himself, and getting dressed. Controlling the shoulder pain is therefore important. The multidisciplinary team has agreed that the patient should wear a sling when he goes for a longer walk in order to support and protect the shoulder. The occupational therapist provides him with a custom-made sling. However, the patient cannot put the sling on himself, so he always has to ask for help before he can go for a walk. He just cannot remember the right way to put on the sling and which steps he needs to follow. The patient decides, together with the occupational therapist, that the goal for the next sessions will be to learn how to put on the sling independently.

Organization

The patient will always be able to perform the task while sitting on his bed or in a chair in a calm environment with few distractions. The patient therefore practices the task

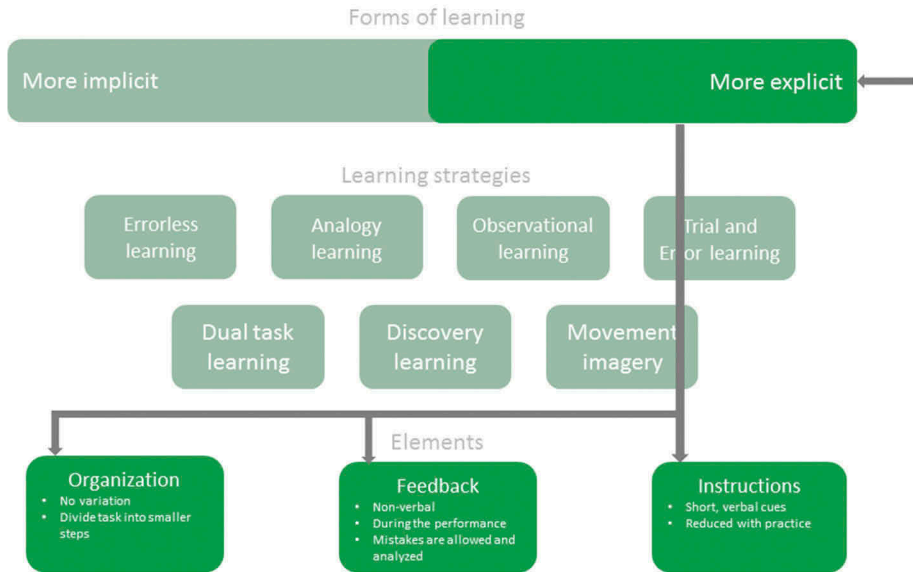

Figure 4. Choices within framework for patient B.

in this environment and the therapist does not vary the environmental conditions (i.e. blocked practice). During observation of the performance of the task, the therapist noticed that the patient encounters problems with three steps within performance: (1) organizing the sling before starting (preparation), (2) choosing the correct loop to begin with, and (3) putting his affected hand into the sling so that it is adequately supported. During practice, the task is therefore divided into three steps.

Instructions

The therapist, along with the patient, devises a couple of short, verbal instructions and cues (e.g. "sling straight on lap," "big loop first," "check wrist") and writes these down. In the beginning, the therapist repeats these cues before the start of the performance. Later, she asks the patient to repeat them himself. After a couple of successful repetitions, no instructions prior to the performance are provided any more. The patient acquired verbal knowledge (i.e. rules and facts) about the task in advantage of the performance.

Feedback

Since the therapist mostly gives verbal instructions about the steps in advance (feedforward), she limits the feedback to nonverbal cues by nodding when the patient performs the steps correctly. In case the patient makes a mistake, she does not interrupt him but rather waits to see whether he can manage himself. She helps by using prompting questions (e.g. "what did go wrong?") and statements ("try it yourself, you can do this"). If the patient cannot solve the problem, she advices him to restart from the beginning.

Patient B, after 6 weeks. Meanwhile, the patient has been discharged and follows an outpatient program. During evaluation of his current situation with the therapist, the patient states that he is able to put on the sling independently at home. He still is aware of the three steps and the cues and repeats them in his head when performing the task. He admits that he cannot put on the sling when he is interrupted or distracted; however, as this does not happen regularly, it is not a problem. As the pain diminishes, he thinks that he can try to reduce the use of the sling.

Discussion

The framework presented in this article may help therapists working in neurorehabilitation to make choices about the application of motor learning in daily practice. In addition, the framework might support the exchange of knowledge and experiences among colleagues and to students.

If health-care professionals wish to implement the framework, they should consider the following issues. First, the framework is a recommendation and not an intervention protocol that has to be strictly followed. It provides an overview of options for the application of motor learning in a patient-tailored way. Guidelines present more general advice on how to implement motor learning, for example, that therapy should be intensive, task-focused, motivating, and patient-tailored (e.g. adjusting tasks to their limits), that the task to be practiced should be meaningful, and that therapists should give feedback and include enough breaks (Kleim and Jones, 2008; Royal Dutch Society for Physical Therapy, 2014). In daily practice, however, these recommendations need to be further specified and individualized (Sullivan, 2010). Therapists and other health-care professionals are faced with the challenging task to make choices every day such as "Which instructions do I give?", "Which feedback should I provide and how should I time it?", "How do I present the task?", and "How do I organize therapy?" It is important to have an overview of the many options within motor learning to make a well-informed choice. The framework provides such an overview and can therefore support therapists during the process of clinical reasoning.

Second, therapists need to realize that neurorehabilitation research has not yet produced enough evidence on motor learning to give clear indications which form of learning is most suitable for which patient. However, some options within motor learning seem to be more effective and work better in specific situations (Appendices 1–3). For example, implicit learning appears to make fewer demands on the working memory, so there is more "free" capacity for the performance of a second task (e.g. walking and talking at the same time – dual-task learning) (Masters and Poolton, 2012; Maxwell, Masters, and Eves, 2003). Therefore, it is hypothesized that people who have difficulties regarding working memory and speed of information processing due to neurological disorders seem to benefit more from implicit learning than explicit learning (Steenbergen et al., 2010). There is some evidence in stroke (Kleynen et al., 2014b), Parkinson's disease (Jie et al., 2016), and Alzheimer's (van Tilborg, Kessels, and Hulstijn, 2011; White et al., 2014) to support this hypothesis.

Third, the framework presents a classification of the seven learning strategies into more implicit and more explicit strategies. This classification is based on theories and opinions of experts. In practice, the way a learning strategy is applied will finally determine whether it has a more implicit or explicit character. Each strategy will become more explicit when a therapist provides a larger number of verbal explanations about the details of the motor skill. Further, the framework is not a complete list of all learning strategies and elements (Kleynen et al., 2015). Strategies such as incidental learning and differential learning (Kleynen et al., 2014a; Schollhorn, 2016) have not been included in it.

Finally, there is a great amount of literature about motor learning. Various models and theories to explain motor learning (i.e. motor control theories) have been published. These theories explain why someone moves in a particular way under particular circumstances. Well-known examples of these theories are the motor program theory (Schmidt, 1975) and dynamic systems theory (Bongaardt and Meijer, 2000), but these are not direct components of the framework. They are obviously important because they could form the theoretical basis for a decision to particular motor learning option. Sufficient insight into the way a patient is moving and why he/she is moving in this way is key to identifying the difficulties they face when moving, to search for a suitable approach to apply in the treatment plan and to evaluate and, if necessary, adjust the chosen approach (Magill, 2011). In addition, the framework is based on a behavioral view of motor learning. When choosing a motor learning option, therapists should also consider neurophysiological recovery processes and expectations regarding prognosis (e.g. for stroke) (Kollen, Kwakkel, and Lindeman, 2006; Kollen et al., 2005; Kwakkel, Kollen, and Lindeman, 2004). Within the framework and the current article, we focused on the options to apply motor learning in practice ("what is done to the patient"). More information about the underlying neurophysiological and psychological mechanism of learning in patient with neurological disorders, also in relation to recovery processes, can be found in literature (Kleim and Jones, 2008; Krakauer, 2015).

Keeping the abovementioned issues in mind, physiotherapists, occupational therapists, and other health-care professional involved in motor learning of patients can use the framework to support their choice within all the different motor learning options. This overview can especially be useful for health-care professionals with less experience or for novices. Experienced therapists can also refer to the framework when they want to test or evaluate their decisions or make them more explicit. For this purpose, the framework might be used in different ways. Researchers often choose between implicit or explicit learning (i.e. the top layer of the framework) and then find suitable strategies and elements. In daily practice, therapists more often seem to start at the bottom layer of the framework. They look at the characteristics of their patient, the tasks that need to be carried out, and the learning stage, subsequently choose from among the elements (i.e. bottom layer) (Kleynen et al., 2017). After that, the therapists link their choice to a learning strategy and a form of learning.

The framework might also be used to support communication and alignment with colleagues in an interdisciplinary team. Motor learning represents a relatively permanent change in motor behavior (Schmidt and Lee, 2011). Changing a patient's motor behavior requires a lot of practice and repetition, as well as varying the environment and the characteristics of the task. In daily practice, however, the number of therapy sessions is limited. It is therefore important for the patients to make the most of all the available possibilities including unguided therapy to practice and repeat movements. A patient's improvement depends on an interdisciplinary approach and the involvement of the patient's system (de Weerdt and Feys, 2002; Langhorne, Bernhardt, and Kwakkel, 2011). When a therapist has found a suitable approach for a particular patient, it seems efficient to apply this approach as much and as consequent as possible. It is therefore important to make agreements with patients and colleagues about therapy goals, division of responsibilities, and the approach to be used. In practice, however, alignment seems to be focusing mostly on goal setting ("What is being practiced?") and less on the approach used to attain this goal ("How is the therapy designed and which approach is being used?") (Stevens, Moser, Köke, and van der Weijden, 2016). The framework could be supportive for the team communication by providing a common terminology and a collective overview. The framework and the motor learning options linked to it could also be used for more unambiguous description, to ensure alignment between colleagues regarding the therapeutic approach when transferring a patient to another setting.

Conclusion and future research

The presented framework provides a possible taxonomy and overview to assist well-informed decisions for motor learning that fit clinical reasoning. The exact implementation of the framework in the selection process and communication should be determined and tested in different settings. Research into user experience and evaluation of the implementation of the framework in different settings is a logical next step. Based on research and future insights, the framework could be adjusted, expanded, and further substantiated.

Declaration of interest

The authors declare no conflict of interest.

Funding

This work was supported by the Nationaal Regieorgaan Praktijkgericht Onderzoek SIA, RAAK Pro [2014-01-49PRO].

ORCID

Melanie Kleynen http://orcid.org/0000-0002-6543-6994

References

Beek PJ, Roerdink R 2014 Evolving insights into motor learning and their implications for neurorehabilitation. In: Selzer M, Clarke S, Cohen L, Kwakkel G, Miller R Eds Textbook of Neural Repair and Rehabilitation (2nd) pp. 95–104. Cambridge, Cambridge University Press.

Benjaminse A, Welling W, Otten B, Gokeler A 2015 A Novel methods of instruction in ACL injury prevention programs, a systematic review. Physical Therapy in Sport 16: 176–186.

Berry DC, Broadbent DE 1998 Interactive tasks and the implicitexplicit distinction. British Journal of Psychology 79: 251–272.

Bobath B 1990 Adult Hemiplegia: evaluation and Treatment, 3rd edn. Oxford, Butterworth-Heinemann.

Bongaardt R, Meijer OG 2000 Bernstein's theory of movement behavior: Historical development and contemporary relevance. Journal of Motor Behavior 32: 57–71.

Braun S, Kleynen M, Schols J, Schack T, Beurskens A, Wade D 2008 Using mental practice in stroke rehabilitation: A framework. Clinical Rehabilitation 22: 579–591.

Braun S, Kleynen M, Van Heel T, Kruithof N, Wade D, Beurskens A 2013 The effects of mental practice in neurological rehabilitation: A systematic review and meta-analysis. Frontiers in Human Neuroscience 7: 390.

Brunnström S 1992 Movement Therapy in Hemiplegia: A Neurophysiological Approach, 2nd edn. Philadelphia, Lippincott Williams and Wilkins.

Buccino G, Vogt S, Ritzl A, Fink GR, Zilles K, Freund HJ, Rizzolatti G 2004 Neural circuits underlying imitation learning of hand actions: An event-related fMRI study. Neuron 42: 323–334.

Capio CM, Poolton JM, Sit CH, Eguia KF, Masters RS 2013 Reduction of errors during practice facilitates fundamental movement skill learning in children with intellectual disabilities. Journal of Intellectual Disability Research 57: 295–305.

Casamassima F, Ferrari A, Milosevic B, Ginis P, Farella E, Rocchi L 2014 A wearable system for gait training in subjects with Parkinson's disease. Sensors 14: 6229–6246.

Cirstea CM, Ptito A, Levin MF 2006 Feedback and cognition in arm motor skill reacquisition after stroke. Stroke 37: 1237–1242.

Davies PM 1985 Steps to Follow: A Guide to the Treatment of Adult Hemiplegia, Berlin, Springer.

De Weerdt W, Feys H 2002 Assessment of physiotherapy for patients with stroke. Lancet 359: 182–183.

De Werd MM, Boelen D, Rikkert MG, Kessels RP 2013 Errorless learning of everyday tasks in people with dementia. Clinical Interventions in Aging 8: 1177–1190.

Dechamps A, Fasotti L, Jungheim J, Leone E, Dood E, Allioux A, Robert PH, Gervais X, Maubourguet N, Olde Rikkert MG, Kessels RP 2011 Effects of different learning methods for instrumental activities of daily living in patients with Alzheimer's dementia: A pilot study. American Journal of Alzheimer's Disease and Other Dementias 26: 273–281.

Depaul VG, Wishart LR, Richardson J, Thabane L, Ma J, Lee TD 2015 Varied overground walking training versus body-weight-supported treadmill training in adults within 1 year of stroke: A randomized controlled trial. Neurorehabilitation and Neural Repair 29: 329–340.

Dickstein R, Deutsch JE 2007 Motor imagery in physical therapist practice. Physical Therapy 87: 942–953.

Durham K, Van Vliet PM, Badger F, Sackley C 2009 Use of information feedback and attentional focus of feedback in treating the person with a hemiplegic arm. Physiotherapy Research International 14: 77–90.

Ertelt D, Hemmelmann C, Dettmers C, Ziegler A, Binkofski F 2012 Observation and execution of upper-limb movements as a tool for rehabilitation of motor deficits in paretic stroke patients: Protocol of a randomized clinical trial. BMC Neurology 12: 42.

Fasoli SE, Trombly CA, Tickle-Degnen L, Verfaellie MH 2002 Effect of instructions on functional reach in persons with and without cerebrovascular accident. American Journal of Occupational Therapy 56: 380–390.

Fisher BE, Morton SM, Lang CE 2014 From motor learning to physical therapy and back again: the state of the art and science of motor learning rehabilitation research. Journal of Neurologic Physical Therapy 38: 149–150.

Fitts PM, Posner MI 1967 Human Performance, Belmont, CA, Brooks/Cole.

Fritz NE, Cheek FM, Nichols-Larsen DS 2015 Motor-cognitive dual-task training in persons with neurologic disorders: A systematic review. Journal of Neurologic Physical Therapy 39: 142–153.

Jie LJ, Goodwin V, Kleynen M, Braun SM, Nunns M, Wilson M 2016 Analogy learning in Parkinson's; As easy as a walk on the beach: A proof-of-concept study. Internationa Journal of Therapy and Rehabilitation 23: 123–130.

Kal EC, Van Der Kamp J, Houdijk H 2013 External attentional focus enhances movement automatization: A comprehensive test of the constrained action hypothesis. Human Movement Science 32: 527–539.

Kal EC, van Der Kamp J, Houdijk H, Groet E, van Bennekom CA, Scherder EJ 2015 Stay focused! The effects of internal and external focus of attention on movement automaticity in patients with stroke. PLoS One 10: e0136917.

Kal EC, Winters M, Van Der Kamp J, Houdijk H, Groet E, Van Bennekom C, Scherder E 2016 Is implicit motor learning preserved after stroke? A systematic review with meta-analysis. PloS One 11: e0166376.

Kim GJ, Hinojosa J, Rao AK, Batavia M, O'Dell MW 2017 Randomized trial on the effects of attentional focus on motor training of the upper extremity using robotics with individuals after chronic stroke. Archives of Physical Medicine and Rehabilitation 98: 1924–1931.

Kitago T, Krakauer JW 2013 Motor learning principles for neurorehabilitation. Handbook of Clinical Neurology 110: 93–103.

Kleim JA, Jones TA 2008 Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage. Journal of Speech, Language, and Hearing Research 51: S225–239.

Kleynen M, Bleijlevens MH, Beurskens AJ, Rasquin SM, Halfens J, Wilson MR, Masters RS, Lexis MA, Braun SM 2013a Terminology, taxonomy, and facilitation of motor learning in clinical practice: Protocol of a delphi study. JMIR Research Protocols 2: e18.

Kleynen M, Braun SM, Beurskens AJ, Verbunt JA, De Bie RA, Masters RS 2013b Investigating the dutch movement-specific reinvestment scale in people with stroke. Clinical Rehabilitation 27: 160–165.

Kleynen M, Braun SM, Bleijlevens MH, Lexis MA, Rasquin SM, Halfens J, Wilson MR, Beurskens AJ, Masters RS 2014a Using a Delphi technique to seek consensus regarding definitions, descriptions and classification of terms related to implicit and explicit forms of motor learning. PloS One 9: e100227.

Kleynen M, Braun SM, Rasquin SM, Bleijlevens MH, Lexis MA, Halfens J, Wilson MR, Masters RS, Beurskens AJ 2015 Multidisciplinary views on applying explicit and implicit motor learning in practice: An international survey. PloS One 10: e0135522.

Kleynen M, Moser A, Haarsma FA, Beurskens AJ, Braun SM 2017 Physiotherapists use a great variety of motor learning options in neurological rehabilitation, from which they choose through an iterative process: A retrospective think-aloud study. Disability and Rehabilitation 39: 1729–1737.

Kleynen M, Wilson MR, Jie LJ, Te Lintel Hekkert F, Goodwin VA, Braun SM 2014b Exploring the utility of analogies in motor learning after stroke: A feasibility study. International Journal of Rehabilitation Research 37: 277–280.

Knott M, Voss DE 1986 Proprioceptive Neuromuscular Facilitation, New York, Harper and Row.

Kollen BJ, Kwakkel G, Lindeman E 2006 Functional recovery after stroke: A review of current developments in stroke rehabilitation research. Reviews on Recent Clinical Trials 1: 75–80.

Kollen BJ, Lennon S, Lyons B, Wheatley-Smith L, Scheper M, Buurke JH, Halfens J, Geurts AC, Kwakkel G 2009 The effectiveness of the Bobath concept in stroke rehabilitation: What is the evidence? Stroke 40: e89–97.

Kollen BJ, Van De Port I, Lindeman E, Twisk J, Kwakkel G 2005 Predicting improvement in gait after stroke: A longitudinal prospective study. Stroke 36: 2676–2680.

Krakauer JW 2015 The applicability of motor learning to neurorehabilitation. In: Dietz V, Ward N Eds Oxford Textbook of Neurorehabilitation, Oxford, UK, Oxford University Press.

Kwakkel G, Kollen B, Lindeman E 2004 Understanding the pattern of functional recovery after stroke: Facts and theories. Restorative Neurology and Neuroscience 22: 281–299.

Lam WK, Maxwell JP, Masters RS 2009 Analogy versus explicit learning of a modified basketball shooting task: Performance and kinematic outcomes. Journal of Sports Science 27: 179–191.

Landers MR, Hatlevig RM, Davis AD, Richards AR, Rosenlof LE 2016 Does attentional focus during balance training in people with Parkinson's disease affect outcome? A randomised controlled clinical trial. Clinical Rehabilitation 30: 53–63.

Langhorne P, Bernhardt J, Kwakkel G 2011 Stroke rehabilitation. Lancet 377: 1693–1702.

Legg L, Langhorne P Outpatient Service Team 2004 Rehabilitation therapy services for stroke patients living at home: Systematic review of randomised trials. Lancet 363: 352–356.

Liao CM, Masters RS 2001 Analogy learning: A means to implicit motor learning. Journal of Sports Science 19: 307–319.

Magill RA 2011 Motor Learning and Control: concepts and Application, 9th edn. New York, McGraw-Hill.

Magill RA, Hall KG 1990 A review of the contextual interference effect in motor skill acquisition. Human Movement Science 9: 241–289.

Malouin F, Richards CL, Jackson PL, Lafleur MF, Durand A, Doyon J 2007 The kinesthetic and visual imagery questionnaire (KVIQ) for assessing motor imagery in persons with physical disabilities: A reliability and construct validity study. Journal of Neurologic Physical Therapy 31: 20–29.

Masters RS 1992 Knowlegde, knerves and know-how: The role of implicit versus explicit knowlegde in the breakdown of a complex motor skill under pressure. British Journal of Psychology 83: 343–356.

Masters RS, Lo CY, Maxwell JP, Patil NG 2008 Implicit motor learning in surgery: Implications for multi-tasking. Surgery 143: 140–145.

Masters RS, Maxwell JP 2004 Implicit motor learning, reinvestment andmovement disruption: what you don't know won't hurt you? In: Williams AM, Hodges NJ Eds Skill Acquisition in Sport: research, Theory and Practice, London, Routledge.

Masters RS, Pall HS, Macmahon KM, Eves FF 2007 Duration of Parkinson disease is associated with an increased propensity for "reinvestment". Neurorehabilitation and Neural Repair 21: 123–126.

Masters RS, Polman RCJ, Hammond NV 1993 'Reinvestement': A diminsion of personalty implicated in skill breakdowm under pressure. Personality and Individual Differences 14: 665–666.

Masters RS, Poolton J 2012 Advances in implicit motor learning. In: Hodges NJ, Williams AM Eds Skill Acquisition in Sport: research, Theory and Practice (2nd edn). London, Routledge.

Maxwell JP, Masters RS, Eves FF 2003 The role of working memory in motor learning and performance. Consciousness and Cognition 12: 376–402.

McCulloch K 2007 Attention and dual-task conditions: Physical therapy implications for individuals with acquired brain injury. Journal of Neurologic Physical Therapy 31: 104–118.

McIsaac TL, Lamberg EM, Muratori LM 2015 Building a framework for a dual task taxonomy. BioMed Research International 2015: 591475.

Mount J, Pierce SR, Parker J, Diegidio R, Woessner R, Spiegel L 2007 Trial and error versus errorless learning of functional skills in patients with acute stroke. NeuroRehabilitation 22: 123–132.

Muratori LM, Lamberg EM, Quinn L, Duff SV 2013 Applying principles of motor learning and control to upper extremity rehabilitation. Journal of Hand Therapy 26: 94–103.

Nijland RH, Van Wegen EE, Harmeling-Van Der Wel BC, Kwakkel G, Investigators E 2010 Presence of finger extension and shoulder abduction within 72 hours after stroke predicts functional recovery: Early prediction of functional outcome after stroke: the EPOS cohort study. Stroke 41: 745–750.

Orrell AJ, Eves FF, Masters RS 2006 Motor learning of a dynamic balancing task after stroke: Implicit implications for stroke rehabilitation. Physical Therapy 86: 369–380.

Pollock A, Baer G, Campbell P, Choo PL, Forster A, Morris J, Pomeroy VM, Langhorne P 2014 Physical rehabilitation approaches for the recovery of function and mobility following stroke. Cochrane Database of Systematic Reviews 4: CD001920.

Pollock A, Baer G, Langhorne P, Pomeroy V 2007 Physiotherapy treatment approaches for the recovery of postural control and lower limb function following stroke: A systematic review. Clinical Rehabilitation 21: 395–410.

Rasquin SM, Verhey FR, Lousberg R, Lodder J 2005 Cognitive performance after first ever stroke related to progression of vascular brain damage: A 2 year follow up CT scan study. Journal of Neurology, Neurosurgery and Psychiatry 76: 1075–1079.

Rasquin SM, Verhey FR, Lousberg R, Winkens I, Lodder J 2002 Vascular cognitive disorders: Memory, mental speed and cognitive flexibility after stroke. Journal of the Neurological Sciences 203: 115–119.

Rasquin SM, Welter J, Van Heugten CM 2013 Course of cognitive functioning during stroke rehabilitation. Neuropsychological Rehabilitation 23: 811–823.

Reber A 1967 Implicit learning of artificial grammars. Journal of Verbal Learning and Verbal Behavior 6: 855–863.

Reber AS 1993 Implicit Learning and Tacit Knowledge: an Essay on the Cognitive Unconscious, New York, Oxford University Press.

Royal Dutch Society for Physical Therapy 2014 Clinical Practice Guideline for Physical Therapy in Patients with Stroke, KNGF. Amersfoort, The Netherlands. https://www.fysionet-evidencebased.nl/index.php/kngf-guidelines-in-english

Sale P, Franceschini M 2012 Action observation and mirror neuron network: A tool for motor stroke rehabilitation. European Journal of Physical and Rehabilitation Medicine 48: 313–318.

Schmidt RA 1975 A schema theory of discrete motor skill learning. Psychological Review 82: 225–260.

Schmidt RA, Lee TD 2011 Motor Control and Learning: A Behavioral Emphasis, 5th edn. p. p 327. Champaign, IL, Human Kinetics.

Schollhorn WI 2016 Invited commentary: Differential learning is different from contextual interference learning. Human Movement Science 47: 240–245.

Shea CH, Kohl RM 1991 Composition of practice: Influence on the retention of motor skills. Research Quarterly for Exercise and Sport 62: 187–195.

Shull PB, Jirattigalachote W, Hunt MA, Cutkosky MR, Delp SL 2014 Quantified self and human movement: A review on the clinical impact of wearable sensing and feedback for gait analysis and intervention. Gait and Posture 40: 11–19.

Shumway-Cook A, Woollacott MH 2006 Motor Control: translating Research into Clinical Practice, 3rd edn. Philadelphia, PA: Lippincott Williams and Wilkins.

Simmons L, Sharma N, Baron JC, Pomeroy VM 2008 Motor imagery to enhance recovery after subcortical stroke: Who might benefit, daily dose, and potential effects. Neurorehabilitation and Neural Repair 22: 458–467.

Steenbergen B, Van Der Kamp J, Verneau M, Jongbloed-Pereboom M, Masters RS 2010 Implicit and explicit learning: Applications from basic research to sports for individuals with impaired movement dynamics. Disability and Rehabilitation 32: 1509–1516.

Stevens A, Moser M, Köke A, Van Der Weijden T 2016 The use and perceived usefulness of a patient-specific measurement instrument in physiotherapy goal setting. A Qualitative Study. Musculoskeletal Science and Practice 27: 23–31.

Subramanian SK, Massie CL, Malcolm MP, Levin MF 2010 Does provision of extrinsic feedback result in improved motor learning in the upper limb poststroke? A systematic review of the evidence. Neurorehabilitation and Neural Repair 24: 113–124.

Sullivan KJ 2010 President's Perspective. Evidence for physical therapist practice: How can we reconcile clinical guidelines and patient-centered care? Journal of Neurologic Physical Therapy 34: 52–53.

Van Tilborg IA, Kessels RP, Hulstijn W 2011 How should we teach everyday skills in dementia? A controlled study comparing implicit and explicit training methods. Clinical Rehabilitation 25: 638–648.

Van Vliet PM, Wulf G 2006 Extrinsic feedback for motor learning after stroke: What is the evidence? Disability and Rehabilitation 28: 831–840.

Veerbeek JM, Kwakkel G, Van Wegen EE, Ket JC, Heymans MW 2011a Early prediction of outcome of activities of daily living after stroke: A systematic review. Stroke 42: 1482–1488.

Veerbeek JM, Van Wegen EE, Harmeling-Van Der Wel BC, Kwakkel G, Investigators E 2011b Is accurate prediction of gait in nonambulatory stroke patients possible within 72 hours poststroke? The EPOS study. Neurorehabilitation and Neural Repair 25: 268–274.

White L, Ford MP, Brown CJ, Peel C, Triebel KL 2014 Facilitating the use of implicit memory and learning in the physical therapy management of individuals with Alzheimer disease: A case series. Journal of Geriatric Physical Therapy 37: 35–44.

Williams AM, Ward P, Knowles JM, Smeeton NJ 2002 Anticipation skill in a real-world task: measurement, training, and transfer in tennis. Journal of Experimental Psychology: Applied 8: 259–270.

Winstein CJ, Pohl PS, Lewthwaite R 1994 Effects of physical guidance and knowledge of results on motor learning: Support for the guidance hypothesis. Research Quarterly for Exercise and Sport 65: 316–323.

Wulf G, Landers M, Lewthwaite R, Tollner T 2009 External focus instructions reduce postural instability in individuals with Parkinson disease. Physical Therapy 89: 162–168.

Appendix 1. Overview of learning strategies from the framework

Strategy	Description	Explanation	Classification and background	Implementation examples	Presumed advantages and conditions	Tools and examples
Errorless learning (EL)	Learning facilitated by constraining the learning environment (e.g. instructions, difficulty of skill) so that very few errors occur.	• Learning proceeds with as few errors as possible. • Mistakes can be prevented in several ways (see implementation examples).	*Classification* Errorless learning is classified under the more implicit strategies. *Background* If no mistakes are made, the learner needs to reflect less on the movement and requires less verbal knowledge.	Errors can be prevented, for example, by • arranging the physical environment in such a way that the learner will make few or no errors; • adjusting the tasks (e.g. practicing sub-tasks); • demonstrating (e.g. by the therapist or other patients); • using instructions (which however makes the strategy more explicit).	*Advantages* • Evidence increases especially for patients with memory problems (De Werd, Boelen, Rikkert, and Kessels, 2013). • EL can be motivating. • If the environment is used to prevent errors, EL can be designed so as to be very implicit (minimal explanation). *Conditions* • Need for clear team agreements with regard to the approach. • Consistent approach is essential.	*Tools* Targeted adjustments of the environment, preferably without the patient becoming aware of it. *Examples from literature* • Orrell, Eves, and Masters, 2006 • White et al., 2014 • Mount et al., 2007
Analogy learning (AL)	Learning facilitated by metaphors. The complex structure of the skill to be learned is integrated into a simple metaphor that the learner is provided with.	• The structure of the skill to be learned is integrated into a simple metaphor.	*Classification* AL is classified under the more implicit strategies. *Background* AL includes brief instructions without extensive facts and rules. This puts less strain on the working memory of the learner and he/she is probably less aware of the exact performance of the task.	• Use of instructions like *"pretend you are …"* • Using a metaphor or suggesting a picture of the situation. • Example: *"Walk as if you're following footprints in the sand."* to influence steps length, gait velocity and gait symmetry (Jie et al., 2016). • Note: The interpretation of the pictured analogy is something that should be determined for each individual patient.	*Advantages* • Limited verbal instructions. • Patients are positive (Kleynen et al., 2014b; Jie et al., 2016). • Patients or family can be involved in finding the analogy. *Conditions* • The analogy should be meaningful to the patient. • Analogy should lead to the right change of the movement. • Not all tasks can be used for analogy (e.g. it is more difficult to find an appropriate analogy for ADL tasks).	*Tools* The metaphor can be supported with a photo of a particular situation. *Examples from literature* • Jie et al., 2016 • Kleynen et al., 2014b • Lam, Maxwell, and Masters, 2009

(*Continued*)

(Continued).

Strategy	Description	Explanation	Classification and background	Implementation examples	Presumed advantages and conditions	Tools and examples
Dual-task learning (DTL)	Learning a skill while simultaneously performing another task. The second task can be a motor or cognitive task but must be attention-demanding.	• During the learning process, a second task is performed. • The choice of a second task is essential: it should be difficult enough to take up a large part of the working memory, but not too difficult to make it impossible to perform the primary motor task.	*Classification* DTL is classified under the more implicit strategies. *Background* During DTL the working memory will be (partly) "blocked" by performing the second task. This way the learner can pay little or no attention to details of the performance of the primary motor task.	• Distracting conversations while patient is for instance walking on a treadmill. • Carrying objects and walking. • Doing calculations while performing a task. • Balance training during performance of grasp and reach tasks (e.g. fastening trousers while standing at the toilet). • Dual-task conditions are also used in practice as a test strategy to test the stability of the task learned.	*Advantages* • Daily life often requires performance under dual-task conditions. • DTL is especially useful for the later stages of the learning process, to achieve a more automatic performance. *Conditions* • Appropriate choice of dual task.	*Tools* Outline of dual-task condition (McIsaac, Lamberg, and Muratori, 2015). *Examples from literature* • McCulloch, 2007 • Fritz, Cheek, and Nichols-Larsen, 2015
Discovery learning (DL)	Learning without guidance or feedback from another person or information source.	• By performing, the learner discovers independently (without explanation or feedback) how to carry out a motor task. • The therapist can provide guidance by adjusting the environment (guided discovery).	*Classification* No unambiguous classification possible. DL is described in the literature as an implicit (Liao and Masters, 2001) or explicit strategy (Williams, Ward, Knowles, and Smeeton, 2002). *Background* How the process of DL develops depends on the patient. Even without instructions, patients can search and discover more details and rules of the movement by themselves, which would make the learning process more explicit.	• Performance of a new task without specific instructions ("Give it a try"). • Performance of a familiar task in a new environment.	*Advantages* • Therapist can observe how the patient deals with a new situation without instructions or specific feedback. *Conditions* • In the end, the learner should receive a form of confirmation on how the therapy session went.	*Tools* Targeted adjustment to environmental factors (e.g. different chairs when learning how to get up, different surfaces when learning how to walk). *Examples from literature* • Orrell, Eves, and Masters, 2006

(*Continued*)

(Continued).

Strategy	Description	Explanation	Classification and background	Implementation examples	Presumed advantages and conditions	Tools and examples
Observational learning (OL)	Learning by observing a movement. The observer determines the key spatial and/or temporal features of the task through observation, thereby creating a cognitive representation of the action pattern.	The movement is learned by imitating a task or movement. The literature also uses the terms "action observation" and "modeling."	*Classification* No unambiguous classification possible. *Background* How the process of OL develops depends mainly on the way the therapist provides instructions. General instructions ("Look at me and imitate what I do") will probably lead to a more implicit form of learning, while specific instructions ("Look at how my elbow stretches when I reach for something") might lead to a more explicit form of learning.	Demonstrations can be given by • a therapist; • husband or wife; • other people (in public); • other patients in group therapy.	*Advantages* • Suitable for patients with communication difficulties as no explanation is needed. • Convincing evidence for neurophysiological mechanism of observational learning (mirror neurons) (Buccino et al., 2004; Sale and Franceschini, 2012). *Conditions* • Patient needs sufficient attention to observe the demonstration. • Demonstration should suit the patient's level. A perfect performance (by healthy people walking) can be confronting for some patients.	*Tools* Video recordings of the performance of the task/movement. *Examples from literature* • Van Tilborg, Kessels, and Hulstijn, 2011 • Ertelt et al., 2012 • Dechamps et al., 2011
Trial-and-error learning (TEL)	Learning by repeatedly attempting to perform a task, during which the learner detects errors and corrects them.	Patient learns from making errors. He/she acknowledges the error, analyzes it, and adjusts the performance.	*Classification* More explicit strategy *Background* Patient is assumed to analyze the movement/error and acquire knowledge of the details of the movement. Therefore, this strategy is classified as more explicit learning.	• The therapist can make use of a more complex, busier environment to provoke errors and difficulties. • The therapist can ask the patient to describe what he/she does or has done, and what went well and what went wrong and why (analysis of the error).	*Advantages* • Therapist gains understanding of the patient's own solutions and his/her problem solving. *Conditions* • Patient should be able to recognize their own errors to learn from them. • "Unsuccessful" attempts should be alternated with successful performance to prevent that the patient becomes demotivated.	*Tools* – *Examples from literature* • Mount et al., 2007

(*Continued*)

(Continued).

Strategy	Description	Explanation	Classification and background	Implementation examples	Presumed advantages and conditions	Tools and examples
Movement Imagery (MI)	Learning by imagining oneself performing the skilled movement (in the first- or third-person perspective) without actually physically performing the movement.	Patient imagines him/herself performing the movement without physically performing it. Imagination alternates with actual performance. Imagining a movement is called "movement imagery." If it is applied systematically as a form of training, the term "mental practice" is used in literature.	*Classification* No unambiguous classification possible. *Background* See observational learning.	• The ratio of repetition (e.g. imagining twice, performing once) depends on the patient's cognitive and motor abilities. • Patients can imagine the movement from their own perspective (first-person perspective) or by looking at themselves from a distance (third-person perspective).	*Advantages* • After the teaching phase, the patient can use MI to practice on their own. Since the movement does not necessarily have to be performed, movements which are not yet safe to perform can be practiced as well. • Evidence for effects in stroke patients, especially training of upper extremities (Braun et al., 2013). *Conditions* • It is important that the technique of imagining the performance is practiced together with the patient. • The patient should preferably imagine the movement visually and kinesthetically.	*Tools* – Use mental training in combination with relaxation (Braun et al., 2008). – Audiotapes that stimulate the imagination. – Framework for motor learning by Braun et al. (2008). – Questionnaires to find out if the patients can imagine the movements well (e.g. Kinesthetic and Visual Imagery Questionnaire (Malouin et al., 2007)). *Examples from literature* • Dickstein and Deutsch, 2007 • Simmons, Sharma, Baron, and Pomeroy, 2008

Appendix 2. Overview of elements

Examples	Explanation, examples and considerations
Examples of the element of "organization"	
Organization of the practice environment • Protective or open • Simple or complex • Quiet or busy • Limited (environmental constraints) or open (without constraints)	The organization of the environment can be used to make the learning situation easier or more difficult. The ultimate choice of the structure depends on the objective (the situation in which the learner will finally perform the task) and of the learner's abilities (see Appendix 3). For example, in errorless learning, a structure can be used that changes from easy to difficult, so that as few errors as possible will be made. In trial-and-error learning, the therapist may use a more complex and busier environment that provokes errors and difficulties.
Organization of the task • Subdividing the task or practicing the whole task • Blocked or random • Massed or distributed	The way the task is performed can also be organized in several ways. Subdividing the task is especially useful for complex movements that require multiple steps, like getting dressed or making coffee. Cyclical motor task (like walking, cycling) should preferably be practice a whole (Shumway-Cook and Woollacott, 2006). Repetition is important when teaching a task (blocked). However, variation is also important during the learning process ("random practice" or "contextual interference"). The natural variation that the task to be learned requires must be the starting point, i.e. in what situation and with what variations will the patient be performing the motor task. Blocked practice appears to work better during the early learning phase, whereas random practice can improve the performance of a task after a retention period (Kitago and Krakauer, 2013; Magill and Hall, 1990). The training can be organized at a given moment, followed by many repetitions (massed) or divided over a longer period (distributed). The therapist should take two considerations into account: (1) rest periods between sessions/repetitions promote performance and learning of the task (distributed practice) (Kitago and Krakauer, 2013; Shea and Kohl, 1991) and (2) some tasks require a certain frequency of repetition in daily life (e.g. turning the pages while reading or leafing through a book). The patient's exercise tolerance level has also to be considered before making a choice.
Examples of the element of "feedback"	
Shape/content of feedback • Verbal of nonverbal • Knowledge of performance or knowledge of results[#]	Unlike instructions, feedback focuses on the preceding movement (Durham, Van Vliet, Badger, and Sackley, 2009). Feedback can be given verbally or nonverbally (e.g. by nodding). Feedback is mostly given by the therapist, but patients can also provide themselves with feedback, thus adopting a more active role in the learning process (Muratori, Lamber, Quinn, and Duff, 2013). Technologies that can provide patients with feedback even beyond regular therapy times are gaining increased interest (Casamassima et al., 2014; Shull et al., 2014). Videos can also be used as a source of feedback (Subramanian, Massie, Malcom, and Levin, 2010). It seems clear that feedback is useful to support the motor learning process (Van Vliet and Wulf, 2006; Subramanian, Massie, Malcolm, and Levin, 2010) and that positive feedback (reward) can have an important influence on motivation (The Royal Dutch Society for Physical Therapy, 2014). However, there is a lot of uncertainty about the use and content of the feedback. The content of the feedback is often divided into knowledge of performance (KP) and knowledge of results (KR)*. KR focuses on the results of the feedback and the goal of the movement (*"This went well."*), while KP gives information about the quality of the performance of a movement (*"Your arm was not stretched properly."*) (Muratori, Lamberg, Quinn, and Duff, 2013). Both forms of feedback have proved to be useful, also to enhance the quality of the movement (Van Vliet and Wulf, 2006; (Subramanian, Massie, Malcolm, and Levin, 2010). If the therapist wants to implement a more implicit learning method, KR would be preferable, whereas KP seems more suitable for explicit learning.
Timing of the feedback • During or after the performance • Frequency	Therapists can give feedback during the performance (concurrent) or after the performance (terminal) of the movement. It is sometimes necessary to give concurrent feedback in daily practice (e.g. when a patient puts himself in an unsafe situation). However, high-frequency concurrent feedback can complicate performance of the learning process (Winstein, Pohl, and Lewthwaite, 1994). It is advisable to deliberately reduce the frequency of the feedback in the course of the learning process to make the patient more independent ("faded feedback"/"reduced feedback frequency") (Cirstea, Ptito, and Levin, 2006). Eventually, the frequency of the feedback needs to be adjusted to the patient's level and cognitive abilities.
Examples of the element of "instructions"	
Focusing on the task (what) and/or the performance (how)	The therapist can only provide general instructions about the task. These general instructions can be combined with more details on how to perform the task. More detailed instructions about the movement or the progress of the movement will probably facilitate a more explicit form of learning (Kleynen et al., 2015).
External or internal focus of attention	The literature distinguishes between internal and external focus of attention. During performance, a patient can direct his/her focus inwards/internal (on the body and the underlying processes for the movement itself) or outwards/external (on the goal and the effect of the movement). It has been described that healthy persons benefit more from instructions with externally focused attention to achieve a better motor learning result. The underlying idea is that a learner will complicate the automatic course of the movement if they pay attention to the movement itself (also known as "constrained action hypothesis") (Kal, Van Der Kamp, and Houdijk, 2013; Van Vliet and Wulf, 2006). Studies have also confirmed these findings in neurological patients (e.g. during balance tasks by patients who suffer from Parkinson's disease or have had a stroke) (Fasoli, Tromblt, Tickle-Degnen, and Verfaellie, 2002; Wulf, Landers, Lewthwaite, and Tollner, 2009); however, more recent studies failed to replicate the superiority of the use of an external focus (Landers et al., 2016; Kim et al., 2017).

(*Continued*)

(Continued).

Other forms of instruction ● Auditory rhythm ● Music ● Manual help	Also nonverbal instructions can be used to guide the patient. Therapists can apply auditory rhythm and music to instruct the patient to move in a certain rhythm and to adjust the speed and symmetry of the patient's gait (Royal Dutch Society for Physical Therapy, 2014). Therapists can apply manual assistance to make the patient feel how easy/efficient the movement can be, but also as a form of (concurrent) feedback.

#The terms "internal focus" and "external focus" are also used in the literature to describe feedback (Beek and Roerdink, 2014).
*These examples focus on extrinsic, augmented different forms of feedback. The patient can also use intrinsic feedback, which is information based on sensory, visual, and auditory experiences during the movements.

Appendix 3. Checklist of factors that can influence the decision

Factor	Information available about	Explanation, examples and considerations
Learner	Patient's learning style?	Movement-specific reinvestment has been described as a personality factor (preference) that has a moderating effect on motor performance (Masters, Polman, and Hammond, 1993) and can possibly predict whether explicit or implicit interventions are more effective (Kal et al., 2015). There is a questionnaire available to assess the propensity to consciously control movements ("Movement Specific Reinvestment Scale") (Masters, Polman, and Hammond, 1993; Kleynen et al., 2013b). First evidence suggests that stroke patients and patients with Parkinson's in general tend to control their movements more consciously (Masters, Polman, and Hammond, 1993; Masters, Pall, Macmahon, and Eves, 2007).
	Patient's background/experiences regarding movements (e.g. work, hobbies)?	The patient's movement experiences and background characteristics in terms of sports, work, and hobbies could be a suitable input for using metaphors in analogy learning. The patient's culture and living conditions could also influence the decision.
	Patient's motor abilities and prognosis?	Regarding the patient's motor control, the therapist should consider if a natural recovery is possible or if he/she should facilitate compensation mechanisms. Predicting the patient's recovery by means of models taken from the literature is very important to estimate the feasibility of a particular learning goal (Nijland et al., 2010; Veerbeek et al., 2011a; Veerbeek et al., 2011b). Also, sensory impairments should be considered. A patient with disturbed sensory input might tend to more consciously control his/her movements and might need additional augmented feedback.
	Patient's cognitive abilities and prognosis?	It is important to have knowledge of the patient's cognitive abilities. Long-term memory, working memory capacity, speed of information processing, and attention but also executive functions disorders can influence the learning process and the decision to use a particular approach. (See Appendix 1 for comments on the strategies of errorless learning, analogy learning, and trial-and-error learning.)
	Information regarding emotions and/or motivation?	Research has shown that motivation is key to the learning process. The therapist has to consider the patient's motivation and emotions during the therapy. Some learning strategies and elements such as errorless learning and positive feedback can be motivating.
Task	Type of task	Motor tasks can be subdivided in many different ways. For example, tasks can be distinguished: discrete and continuous tasks, open and closed tasks, and phylogenetic and ontogenetic tasks (Magill, 2011; Muratori, Lamberg, Quinn, and Duffl, 2013)) (1) Discrete or continuous tasks: discrete tasks have a clear beginning and ending, while continuous tasks are mostly rhythmic or cyclical without a clear beginning and ending. (See also Appendix 2, "organization") (1) Open and closed tasks: The learner can begin or end a closed task at any moment because the environment does not change (e.g. walking in a quiet practice room). During an open task, the patient has to react to changes in the environment (e.g. walking in a busy shopping street). The therapy usually starts by learning closed tasks. It is also important to practice open tasks during the learning process as these are likely to occur in daily life. (2) Phylogenetic and ontogenetic tasks It is likely that phylogenetic skills, such as walking and postural control, are less easily influenced by conscious, explicit learning interventions because they are usually acquired implicitly early in development.
	In which situation should the task be realized?	Consider the different environments (e.g. home and work), how often the task has to be repeated (see the above comments on the element of "organization"), and the varieties of the task (e.g. does the patient only have to be able to walk the stairs in their own house or will he/she encounter other stairs as well?).
	What is the goal (safely, efficiently, independently, automatically)?	The goal of the motor task can vary. It is important to check whether the patient especially has to be able to perform the task safely and independently and whether the quality of performance of the task is important. The efficiency of the movement may be essential, for instance, as the task needs to be repeated often. The instructions, feedback, and organization of the learning environment should be adjusted to the goal. It is also important to consider if automatic performance of the task is useful and/or achievable. Does the patient always have to perform the task under the same circumstances (e.g. visiting the toilet at home) or is it necessary for them to perform it in other situations (e.g. visiting a toilet in a restaurant)?

(*Continued*)

(Continued).

Factor	Information available about	Explanation, examples and considerations
Learning stage	In which learning stage is the patient?	The literature often distinguishes between three learning stages (Fitts and Posner, 1967), assuming that the learning process starts with a cognitive, conscious (explicit) stage. However, recent studies show that the learning process can also start without an initial cognitive stage. The entire learning process can also be more subconscious (Masters and Maxwell, 2004). Research into the best approach for the different stages in neurorehabilitation is not yet available. When choosing an approach for motor learning in practice, it is important to consider how much experience a patient has had with a motor task, how this has worked out, and how stable the performance of the movement was. Some learning strategies such as errorless learning seem to be more suitable for the early learning stage, while strategies such as dual-task learning are more appropriate for stages in which the patient's performance has become more stable.