

Chapter 10

Epilogue

1. Thesis summary

The ability to perform dual-tasks while moving is often impaired in people with stroke. The aim of this thesis was to investigate the potential of implicit motor learning interventions to target this problem. The rationale was that implicit motor learning should result in relatively automatic movements and thereby enhance dual-task performance in stroke patients. To ensure a comprehensive assessment, the thesis comprised three main parts: reviews of the current evidence, observational studies of current rehabilitation practice, and experimental studies to determine the immediate and longer-term effects of an implicit- versus explicit learning intervention on motor skill, automaticity, and dual-task performance.

In the first part, which is covered by **Chapters 2 and 3**, I systematically reviewed the current evidence regarding implicit motor learning in healthy adults and people with stroke. Specifically, the results of **Chapter 2** suggest that implicit motor learning interventions have a small benefit for dual-task performance compared to explicit motor learning interventions in healthy adults. In addition, the results in **Chapter 3** indicate that the ability for implicit motor learning seems largely preserved after stroke. Importantly, however, in both chapters the strength of the evidence is weak, due to a significant lack of reporting on group selection, randomization, and blinding procedures. Other important limitations of the current literature are the short intervention periods and small samples involved. Also, the results of **Chapter 3** reveal a clear lack of studies that assess implicit motor learning in clinically relevant, dynamically complex motor tasks in people with stroke (e.g., gait or balance tasks); all but one study investigated implicit learning by means of the serial reaction time paradigm.

The second part of this thesis focused on how implicit and explicit motor learning strategies are currently applied within rehabilitation practice, both by patients and physical therapists themselves. First, the results of **Chapter 4** show that it is possible to use a self-report questionnaire – the Movement-Specific Reinvestment Scale – to validly and reliably measure a stroke patient’s general inclination to use conscious (explicit) motor control in daily life. Results further confirm the idea that stroke patients are more strongly inclined to do so than their healthy peers. In **Chapter 5** this scale was used in a different sample of rehabilitating stroke patients. Results show that patients with stronger inclinations for conscious control experience greater reductions in gait speed when they concurrently need to perform a tone-counting dual-task. This provides indirect evidence for the hypothesis that conscious control impairs dual-tasking after stroke. In **Chapter 6**, I show that physical therapists use a balanced mix of more implicit (external focus) instructions and more explicit (internal focus) feedback during inpatient rehabilitation. Interestingly, therapists adapt their use of instructions to the individual patient, using more externally focused statements for patients with a longer length of stay and with a stronger conscious control inclination. Also, therapist-interviews reveal that they tried to rely more on implicit, external focus strategies for patients with cognitive

impairments and relatively intact sensory functioning. As such, the results of **Chapter 6** nuance the findings of **Chapter 5**, as they suggest that – rather than being negative per se – explicit, conscious motor control could be beneficial to performance and learning in particular subgroups of patients.

The third part of this thesis focused on the actual effects of one particular implicit learning intervention – external focus instructions – on movement automaticity and dual-tasking in stroke. First, the results of **Chapter 7** show that external focus instructions can be used to induce implicit motor learning. Specifically, healthy adults show significantly faster leg-stepping performance and increased automaticity with external focus instructions compared to with internal focus instructions. Most importantly, results show that external focus instructions also enhance dual-task performance compared to internal focus instructions. In **Chapter 8**, however, these results cannot be replicated in chronic stroke patients – even though the exact same paradigm is used. Thus, external focus instructions do not benefit patients' leg-stepping performance, automaticity, or dual-task performance. The absence of group level effects seems due to the fact that patients do not uniformly respond to the focus instructions; in this study, patients with weaker conscious control inclinations and better motor skill performed better with external- compared to internal focus instructions (and vice versa). Finally, in **Chapter 9** a randomized controlled trial is described to compare the effectiveness of external and internal focus instructions on *learning* of a more clinically relevant balance board task in rehabilitating stroke patients. Results show a small benefit of external instructions for single-task motor performance after one week of practice. However, after 3 weeks of practice both the external- and internal focus group show similar improvements in balance skill and dual-task performance. Most importantly – similar to **Chapter 8** – the effects of attentional focus seem to depend on certain patient characteristics. In particular, external focus instructions result in more effective learning for patients with better baseline motor skill and sensory functioning, and with worse attention capacity.

Overall, the results of this thesis do not support the hypothesis that implicit motor learning uniformly benefits motor skill, automaticity of movement, and dual-task performance in people with stroke. Rather, the findings in **Chapters 6, 8, and 9** suggest that implicit and explicit motor learning interventions need to be tailored to the individual patient. A patient's motor skill, sensory functioning, attention capacity, and conscious control inclination all seem to influence whether an implicit- or explicit intervention is most effective. In the remainder of this discussion section I will discuss these results in more detail. The aim is to provide leads for future research on this topic, but also to give some (preliminary) guidance for clinical application.

2. What works for whom? Can we tailor implicit and explicit motor learning interventions during rehabilitation after stroke?

The main implication of this thesis for clinical practice is that therapists should strive toward a more tailored approach to motor learning in rehabilitation. Intuitively, this seems plausible. Given the large heterogeneity in the aetiology and clinical manifestations of stroke, it would actually be surprising if one particular motor learning intervention would be superior for all patients in all circumstances. However, the large heterogeneity in (constellations of) impairments simultaneously underlines the complexity of determining the best-fitting motor learning intervention for an individual stroke patient. Successful tailoring thus requires that a therapist knows which patient factors are important, but also how different factors are to be weighed.

While they are by no means conclusive, the results of this thesis shed some light on these issues. Results of Chapters 6, 8, and 9 fairly consistently point to four patient characteristics as potential effect modifiers. These were: Motor skill, cognition/attention, sensory function, and conscious control inclination. In Chapter 6, all four emerge as factors that therapists seem to take into account when selecting either external- (more implicit) or internal focus (more explicit) motor learning strategies in daily practice. Furthermore, all are also found to modify the effects of these interventions in either or both Chapters 8 and 9 – the chapters where I compare the immediate and longer-term effects on motor and dual-task performance.

Figure 10.1 summarizes the results of these three chapters. Importantly, this figure also shows that *how* these four patient characteristics purportedly influence the effectiveness of external and internal focus interventions may depend on the desired timeframe in which effects should be achieved (i.e., immediate vs. longer-term), as well as other task constraints (i.e., single- vs. dual-task conditions). To illustrate this, consider the first characteristic: motor skill. Results of Chapters 6, 8, and 9 suggest that patients' who have better initial motor skill will benefit more from implicit than from explicit interventions. The reverse is also true – patients with worse skill are more likely to benefit from explicit interventions. Importantly, these effects are only evident for *single*-task motor performance and learning; no effects are evident regarding dual-task performance and learning. Below, I will further discuss these findings per characteristic separately in more detail.

		Observational Study (Chapter 6)	Experimental Studies (Chapter 8) (Chapter 9)			
<i>Findings concern:</i>		<i>Experiential knowledge & behavior of physical therapists</i>	<i>Immediate effects on motor performance</i>		<i>Long-term effects on motor learning</i>	
<i>Task Condition:</i>	<i>Patient Characteristic:</i>	General	Single-Task	Dual-Task	Single-Task	Dual-Task
			Motor skill 	IL>EL	IL>EL	IL=EL
Attention/ Cognition 	IL<EL	IL=EL	IL>EL	IL=EL	IL<EL	
Sensory Function 	IL>EL	N/A	N/A	IL>EL	IL>EL	
Conscious control inclination 	IL>EL	IL<EL	IL=EL	IL=EL	IL=EL	

Figure 10.1. Patient characteristics in relation to the relative effectiveness of explicit (internal focus; EL) and implicit (external focus; IL) motor learning interventions per study.

For each study it is presented how each of the four patient characteristics were related to the relative effectiveness of implicit (external focus; IL) and explicit (internal focus; EL) interventions. For the results of Chapters 8 and 9 a further distinction is made between the effects on single-task and dual-task performance.

NB: EL: Explicit motor learning; IL: Implicit motor learning; N/A: not assessed;

2.1. Motor skill

Therapists generally use more explicit, internal focus strategies in early rehabilitation phases, and increase their use of implicit, external focus strategies as rehabilitation progresses (Chapter 6). This also matches their self-reported strategy of switching to more implicit strategies as a patient's motor skill develops. The findings in Chapters 8 and 9 are consistent with this way of working: Patients with less developed motor skills show superior motor performance and learning with internal focus instructions, whereas external focus instructions seem more effective for patients with relatively good motor skill (Figure 10.1).^{††} However, as shown in Figure 10.1, motor skill only influences the effects on *single*-task motor performance and learning; no effects are observed for dual-task performance and learning.

The finding that the effects of implicit and explicit motor learning interventions differ as a function of stroke patients' motor skill is not a surprise finding. Patients' motor skill was identified as one of the most important factors to consider when opting for implicit or explicit strategies in a recent Delphi-study among experts in motor learning research.³¹⁵ Further, there is also experimental work in healthy adults that points to an effect-modifying role of an individual's level of motor skill. Several studies have found that novices show superior performance when they focus internally, whereas skilled individuals benefit more from an external focus.^{217,316} Relatedly, experiments by Beilock and colleagues^{125,317} also showed that motor performance of novices is enhanced when they focus on the task at hand, but is degraded when they are distracted. In contrast, they observed an opposite pattern of results in skilled performers.

My findings and those in healthy adults fit traditional theories of skill acquisition. Fitts and Posner⁴⁶ posited that early in learning (in the verbal-cognitive phase) movements need to be consciously controlled per se. Only with continued practice does motor control gradually become more automatic. This would explain why promoting explicit, conscious control of movement through explicit learning is most beneficial for patients with greater motor impairments - as well as for novice healthy performers. In fact, Wulf and colleagues imply this possibility in their explanation for the generally superior motor learning effects of external focus strategies in healthy adults.^{87,254} Their constrained action hypothesis states that an internal focus intervention hinders performance and learning because it disrupts automaticity. Yet, inherent in this reasoning is the assumption that a certain basic level of motor skill is already established (see also Masters and Maxwell⁹³). While this may be true in many healthy adults, the results of this thesis suggest that this is arguably not the case for many stroke patients - especially early in rehabilitation.

†† It is interesting to note that these results are consistent across studies, even though different assessments of motor skill are used in Chapter 8 (Fügl-Meyer Assessment - lower extremity subscale) than in Chapter 9 (Berg Balance Scale). The reason for using different assessments is that I wanted to use motor skill tests that were most relevant for the motor tasks performed (Chapter 8: Leg-stepping task; Chapter 9: Balance board task).

Clinical message: Consider to predominantly promote explicit learning using internal focus of attention strategies for patients with worse motor skill. Switch to predominantly implicit, externally focused strategies for patients with better developed motor skill. Of note, when the main rehabilitation goal is to improve dual-task performance, motor skill does not seem to be an important factor in choosing for a particular motor learning strategy.

2.2. Cognition/Attention

Therapists most frequently (+/-66%) mention patients' cognitive capacity as important factor when deciding between implicit and explicit strategies (Chapter 6). Specifically, they state that they use more implicit motor learning interventions for patients with greater cognitive impairments. In Chapters 8 and 9 one particular cognitive domain— attention capacity – is found to influence whether external or internal focus instructions are most effective. Also, in both studies this is only observed for dual-task conditions. This suggests that attention capacity only becomes an important effect modifier when it is sufficiently taxed, such as in dual-task conditions.

The way in which attention capacity modifies the effectiveness of focus instructions on dual-task performance differs between Chapters 8 and 9. Intriguingly, for patients with larger attention capacity an external focus results in superior *immediate* dual-tasking improvements (Chapter 8), while an internal focus results in superior *long-term* dual-tasking improvements (Chapter 9). Theoretically, based on the constrained action hypothesis one would predict internal focus instructions to be best suited for individuals with good attention capacity. This because internal focus instructions are thought to be more attention-demanding than external focus instructions.^{87,254} However, this thesis suggests that this prediction only holds true when patients are given sufficient time to practice with their assigned focus (i.e., 3 weeks in Chapter 9).

The discrepancy in short- and long-term results may be due to the focus familiarity of patients. In both chapters 8 and 9, patients generally reported a strong inclination for conscious motor control in daily life. As such, they were more familiar with using an internal focus of attention,²⁴⁰ and therefore probably needed to invest a greater amount of attentional resources to comply with the relatively unfamiliar external focus.^{215,318} In Chapter 8 patients only perform a few trials with each focus of attention, which gives them little opportunity to get accustomed to the 'new' external focus strategy. Hence, in this study, patients with greater attention capacity are better equipped to use an external focus than patients with smaller attention capacity. In Chapter 9, patients practice their focus instruction over a period of 3 weeks. This gives them ample time to get familiar with either instruction. Without differences

in focus familiarity between groups,^{‡‡} patients with greater attention capacity now improve the most with internal focus instructions.^{§§} In short, these results imply that internal focus instructions are best suited for individuals with good attention capacity – but only when there is no confounding effect of focus familiarity.

Besides attention capacity, other cognitive domains (i.e., working memory and executive function) do not modify the effects of external and internal focus of attention in Chapters 8 and 9. Especially the absence of an effect of working memory is notable, considering its central role in implicit motor learning.^{44,93} This might be due to the fact that only one relatively simple (internal or external) focus instruction is used in these studies. It seems that working memory needs to be taxed more profoundly for it to constrain learning. A recent study Buszard et al.⁷³ showed that providing multiple explicit instructions benefits motor learning of children with superior working memory capacity, but actually impairs learning of children with relatively poor working memory capacity.^{cf319} Thus, working memory capacity may also act as effect modifier, depending on the number of explicit instructions/rules provided.

Clinical message: When the main goal is to improve dual-task performance of patients, their attention capacity seems relevant. More implicit, external focus instructions seem more effective for patients with attention capacity impairments. Yet, given that many patients have a strong inclination for conscious control,^{28,29,134} it might take a few practice sessions for them to get used to this unfamiliar focus strategy.

2.3. Sensory function

In Chapter 6, several therapists state that they make more use of explicit (internal focus) strategies for patients with impaired body awareness. Indeed, sensory function turns out to be a quite strong effect modifier in Chapter 9; patients with lower scores on a screening test of touch and proprioception show greater improvements in balance board performance when they practice with internal focus instructions compared to external focus instructions. Effects are consistent for single- and dual-task measures (Figure 10.1).

^{‡‡} This was evidenced by patients' self-reported ability to perform their focus instructions in Chapter 9. After the first session, the internal focus group scored significantly better (23.2 ± 21.7) compared to the external group (37.0 ± 22.5 ; $t(49) = -2.22$, $p = 0.03$; lower scores indicate less difficulty). After the last session, however, scores were similar between groups (internal: 23.2 ± 26.1 ; external: 28.7 ± 20.5 ; $t(48) = -0.829$, $p = 0.41$). Only the external focus group showed a reduction in perceived difficulty of complying with the instructions ($t(24) = 2.050$, $p = 0.05$).

^{§§} Please also note that the patients in Chapter 9 were subacute stroke patients, while those in Chapter 8 were chronic stroke patients. The latter might have found it especially difficult to adjust to a 'new' strategy, because they had used their conscious control strategies for such a long period of time (± 10 years since stroke).

In healthy adults, intact somatosensory feedback is essential for implicit motor control. A powerful illustration hereof is the famous case of Ian Waterman.^{320,321} Due to a gastric flu infection he experienced peripheral nerve damage, resulting in permanent selective loss of all sense of touch and proprioception. Although his motor nerves were spared, he was no longer able to move due to this loss of peripheral feedback. The only way in which he could perform movements was by looking directly at the limbs involved, and investing significant cognitive effort in consciously monitoring and executing the desired skill. After prolonged practice he managed to remaster basic daily motor skills, such as standing upright and walking, and even the ability to drive a car. However, conscious visual control of movement always remains necessary.

In a sense, patients with stroke can suffer from the same problems as Ian Waterman. Accordingly, it seems that when patients no longer have an accurate sense of their body, conscious (visual) control of movement is needed to compensate for this. For those patients, it would make sense to use explicit, internal focus instructions to help them consciously control their movements. In contrast, external focus instructions will be less efficient, as they direct patients' attention away from their body and thereby prevent the patient from making the necessary adaptations to his/her movements (see also Toner & Moran³²² and Shusterman³²³). Further, external instructions will likely also be more attention-demanding: Patients are effectively asked to focus on the effects of their movements *on top of* focusing internally (which they simply need to do regardless). This would explain why internal focus instructions appear superior both for single- *and* dual-task performance in patients with more severe sensory impairments.

The potential role of sensory functioning has received almost no attention in experimental research on implicit motor learning in general and focus of attention in particular. Results of Chapter 9 do seem to fit with a study by Vidoni and Boyd.³²⁴ They explored the relation between proprioceptive deficits (i.e., a limb-position matching task) and motor learning ability in chronic stroke patients. Their paradigm typically induces implicit motor learning: Patients learned to track a continuously moving stimulus on a screen, by moving a joystick with their hemiparetic hand. Unbeknownst to the patients, the stimulus first moved randomly and then followed a specific pattern in each trial (a version of the serial-reaction time paradigm described in Chapter 1). After practice, patients had become significantly better at tracking the repeated segment than at tracking the random segments. However, learning improvements were smaller for patients with greater proprioceptive impairments. This suggests that implicit learning strategies are dependent on the integrity of patients' proprioception. Still, no comparison was made with an explicit learning intervention in this paper, and therefore we must be cautious with this interpretation of results.

Clinical message: More explicit, internal focus strategies seem most beneficial for patients with substantial sensory impairments. Consider to switch towards relatively more implicit, external focus strategies for patients with minimal or no sensory impairments.

2.4. Conscious control inclination

As described in Chapter 6, therapists use relatively more implicit (external focus) strategies for patients with stronger conscious control inclinations. This characteristic only modified the immediate effects of focus instructions on single task motor performance in Chapter 8 (Figure 10.1). This suggests that patients perform best when they receive instructions that fit their conscious control inclinations. Yet, this effect may be restricted to single-task performance and short time scales: In Chapter 9 conscious control inclination does not modify the effects of attentional focus instructions on learning a new balance task over a 3-week period.

Research into the effect modifying role of conscious control inclinations (or focus preferences) in healthy people largely concurs with the findings in Chapter 8. Several studies have shown that motor performance is enhanced when an individual receives focus instructions that he/she prefers or is familiar with.^{215,318,325, cf 299} Studies by Tse et al.²¹⁴ and Maurer and Munzert et al.²¹⁵ further suggest that these effects may also transfer to short-term learning. Tse et al.,²¹⁴ for instance, had young children practice a dart throwing task in one practice session, either using an internal or external focus of attention. At a delayed retention test one week later, those children with a strong conscious control inclination showed greatest improvements in throwing accuracy when they had practiced with an internal focus of attention. Conversely, children with low conscious control inclinations improved most when they had practiced with an external focus instruction. Maurer and Munzert essentially found the same results in healthy adults who practiced a golf-putting task (two practice sessions). In conclusion, it seems best to align focus instructions with an individual's conscious control inclination, but only when effects are to be achieved on short time scales (i.e., within one week).

Time scale may in part explain the absence of an effect modifying role of conscious control inclination in Chapter 9. Different from Chapter 8, and the studies in healthy adults, patients had sufficient time (three weeks) to get accustomed to their particular focus instruction. This likely resulted in an increased task-specific focus familiarity that rendered patients' general conscious control inclination irrelevant (see also section 2.2. "Cognition/Attention"). This idea is supported by the data in Chapter 9: Patients overall had a strong conscious control inclination at baseline ($M=21.5\pm 6.1$). Accordingly, they generally found it more difficult to perform an external focus than an internal focus of attention ($p<0.05$). Yet, after practice this difference in perceived difficulty to focus as instructed had disappeared, even though patients overall still reported a high conscious control inclination ($M=19.5\pm 5.4$) after the intervention.

Clinical message: For short term effects on single-task motor performance, it may be best to provide more explicit, internal focus instructions to patients with stronger conscious control inclinations – and vice versa. However, given sufficient practice, patients’ general conscious control inclination seems less relevant.

2.5. Successful tailoring in practice: How to weigh the relative importance of different factors?

I described how motor skill, attention capacity, sensory function, and conscious control inclination each may separately predict whether implicit or explicit motor learning interventions will be more effective for a particular stroke patient. However, in clinical practice this will often result in conflicting predictions. For instance, what to do if a patient presents with severe motor impairments (suggesting a more explicit, internal focus strategy) *and* severely impaired attention capacity (suggesting a more implicit, external focus strategy)? A key question therefore is: Is there an objective way to judge the relative importance of different effect modifiers when deciding upon a particular motor learning strategy?

Unfortunately, in general for now the answer must be ‘no’. This is uncharted territory. Based on the results of Chapter 9 I did make a decision tree in which a preliminary attempt is made to weigh different patient characteristics – yet this tool now first needs to be put to the test in future studies (see the “Future Directions” section for a detailed discussion). Thus, awaiting this and further evidence, for now I would recommend therapists to rely on their professional experience and intuition to select an appropriate motor learning strategy. The results of this thesis do provide some leads to guide them in this process. That is, one step that may help reduce the number of potentially relevant factors is to consider the therapeutic goal (i.e., improve single- or dual-task performance) and desired timeframe (i.e., immediate effects vs. longer-term effect). For instance, when the goal is to achieve long-term improvements in dual-task performance, a patient’s attention capacity and sensory function seem relevant, whereas motor skill and conscious control inclination do not (or less so; Figure 10.1).

Clinical message: Therapists should rely on their clinical expertise to weigh the patient’s characteristics in order to select proper motor learning strategies. One step that may help to reduce the number of potentially relevant factors is to consider the therapeutic goal (i.e., mainly improve single- or dual-task performance) and desired timeframe in which effects are to be achieved (i.e., immediate effects vs. longer-term effects after multiple practice sessions). Figure 10.1 could give some guidance for this selection.

3. Future directions

3.1. Tailoring

This thesis showed that motor learning interventions could help to improve motor skills and dual-tasking after stroke, but that there is likely not one single approach that will always work best for all patients. An important issue for future research is therefore to further investigate if (and how) we can successfully tailor implicit and explicit interventions to the individual patient. Specifically, future studies are needed that:

1. Validate the four effect modifiers identified in this thesis (motor skill, attention capacity, sensory function, conscious control inclination) and determine whether results generalize to different motor skills (e.g., gait or reach-to-grasp) and/or implicit learning interventions (i.e., analogy-, errorless, and dual-task learning)
2. Explore the importance of other possibly effect modifiers, such as working memory⁷³ and motor imagery capacity³¹³
3. Explore how different combinations of impairments influence the effectiveness of implicit and explicit motor learning interventions after stroke

Ultimately these combined efforts might enable us to develop general guidelines for tailored use of implicit and explicit motor learning interventions post-stroke. To give a tangible example of how these efforts could benefit clinical practice, consider Figure 10.2. Here, I present a decision tree that I created based on the results of the RCT described in Chapter 9. With this tool therapists could tailor implicit and explicit learning strategies when aiming to achieve long-term improvements in balance board performance. I will briefly illustrate how I did this, and how therapists might use this tool.

As a first step, a therapist needs to decide whether his/her primary aim is to achieve long-term improvements in single-task (Figure 10.2.A) or dual-task performance (Figure 10.2.B). Next, the therapist is only needs to consider those characteristics that are relevant to this aim. For instance, when aiming to improve single-task performance, the two characteristics of interest are motor skill (BBS)²³² and sensory functioning (NSA).²³¹ Subsequently, the therapist needs to determine whether the patient meets specific cut-off values for these variables. Using the regression analyses reported in Chapter 9, I determined that external focus instructions resulted in superior improvements in single task performance compared to internal focus instructions for patients with NSA scores >74 and BBS scores > 46. Finally, the therapist needs to weigh these characteristics. For this decision tree, I did this by assigning each patient a score of 0 (both variables indicate internal focus to be superior), 1 (one indicates an internal focus, the other indicates an external focus), or 2 (both suggest an external focus). I then plotted the learning improvements in rotational stiffness for these three groups of patients. This revealed that an external focus resulted in superior improvements in single-task

performance for patients with a score of 2 (both BBS and NSA suggest an external focus), while an internal focus was superior for patients who scored 0-1. This can also be seen in the decision tree – only in case of two positive answers is an external focus recommended (Figure 10.2.A). The decision tree in panel B (for dual-task performance) was made using the same approach.

Admittedly, the resulting decision tree in Figure 10.2 is highly task-specific (e.g., designed for one particular balance paradigm) and needs to be validated in future research. Retrospective application on the data in Chapter 9 confirmed that patients who received their “optimal” focus instruction according to this decision tree achieved significantly greater improvements in rotational stiffness and dual-task sway compared to patients who did not (Mann-Whitney U; $p's \leq 0.035$). Yet, to properly validate this decision tree, we need to test whether the same results are obtained when the tool is used prospectively.

A final remark concerns the limitations of the use of simple rule-based decision trees in clinical practice. Such tools should be used to guide therapists, and serve as an extra tool to extend their own intuitions and clinical reasoning. As eloquently argued by Dreyfus,³²⁶ experts (in any domain) possess intuitive experiential knowledge that is often superior to – and cannot easily be captured by – simple, rule-based procedures. As such, the role of decision trees (like the one presented in Figure 10.2) should be to give guidance to physical therapists' decision making, but certainly not prescribe it. For instance, a decision tree may be very useful to start from for a therapist who starts treatment with a new patient, or in case the current repertoire of motor learning instructions and strategies used does not seem to be particularly effective, and a change of strategy may be needed.

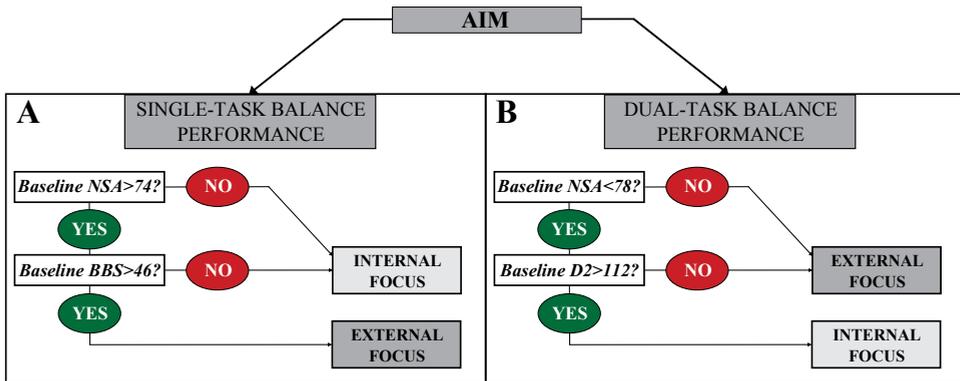


Figure 10.2 Example of decision tree for tailoring focus instructions for the balance board task described in Chapter 9. First, therapists decide whether their main aim is to achieve long-term improvements in single-task (A) or dual-task performance (B). This provides therapists with guidance as to which patient characteristics are relevant, and which are not. Next, based on specific cut-off values on these relevant patient characteristics an external or internal focus strategy is recommended. Retrospective application of the decision tree presented in Figure 10.2 on the data in Chapter 9 confirmed that patients who received their “optimal” focus instruction achieved significantly greater improvements in rotational stiffness and dual-task sway compared to patients who did not (Mann-Whitney U; $p's \leq 0.035$). **NB:** BBS = Berg Balance Scale (0-56; higher scores indicate better balance capacity); D2 = D2-Attention test (0-300; higher scores indicate better attention capacity);²³⁰ NSA = Nottingham Sensory Assessment (0-80; higher scores indicate better sensory function);

3.2. Dual-task training

Future studies may also revisit the paradigm of dual-task training as intervention to improve dual-tasking after stroke. In recent years, several studies in stroke and elderly have reported beneficial effects of dual-task training regimes (i.e., practicing motor and cognitive tasks simultaneously) versus single-task practice schedules (where only the motor task is practiced).^{35,36} These results are usually explained using the framework of Kramer who posited that dual-task training improves a person's ability to appropriately divide attention between two tasks.^{327,328} However, we would then expect to see significant transfer of learning to new dual-task combinations – which is typically not the case.^{38,39} An alternative explanation for the results of dual-task training studies is that they covertly compare implicit with explicit learning. That is, for patients in the dual-task group their working memory is occupied by a secondary task. This restricts their opportunities to process movement related information, resulting in relatively implicit motor learning.^{41,55} By contrast, in these studies the single-task training intervention typically consists of performing several motor tasks in isolation - and apparently without specific constraints put in place to prevent learners from focusing on their movements. It is well known that such an approach generally induces explicit learning.^{41,49}

This raises the question whether dual-task training would also be superior to single-task training when the latter is explicitly designed to induce implicit learning (e.g., by means of external focus instructions).

4. Strengths and limitations

A strength of this thesis is that complementary methods were used to approach the topic of implicit motor learning in rehabilitation after stroke. Combining systematic reviews, observational studies and experimental studies made it possible to link findings from the extant literature and experimental research to observations of clinical practice. For instance, with regard to tailoring of motor learning, similar patterns of results emerged from the observation of clinical practice (Chapter 6) and experimental studies (Chapters 8-9). This further strengthens the confidence in these findings, but also facilitates implementation of the results of this thesis back into practice. Another example is the critical evaluation of the current literature with the systematic reviews, as presented in Chapters 2 and 3. Most importantly, it was found that studies typically involve small samples and short intervention periods, are often not pre-registered, and lack detailed description of group selection, randomization, and blinding. Combined, these issues undermine the validity and reproducibility of (implicit) motor learning research.^{97,129} This analysis of the current literature was essential to carefully design the randomized controlled trial in Chapter 9, and circumvent these methodological pitfalls as much as possible.

An important limitation of this thesis is that the experimental studies were restricted to one implicit motor learning intervention: external focus instructions. This was based on the widespread evidence for, and use of external focus interventions in sports science and practice,^{57,76,77} and the fact that this intervention is gaining more and more attention in neurorehabilitation education and practice.^{78,79} However, it remains to be seen whether the findings of this thesis also apply to other implicit learning interventions, such as analogy-, errorless- and dual-task learning. There is currently at least one randomized controlled trial under way that compares the effects of analogy and explicit learning in chronic stroke – its results are much anticipated.³²⁹

A second limitation of the studies described in this thesis (and of implicit motor learning research in general) is the lack of objective, direct manipulation checks that measure whether the purported implicit interventions really resulted in minimal conscious control of movement. Most studies (including several in this thesis) have assessed performers' movement related knowledge or dual-task performance for this purpose (Chapters 2 and 3). The presumption is that people who move more automatically can tell less about their movements, and show better dual-task performance. While plausible, these are indirect measures; verbal reports are

¶ No pun intended.

collected after the fact, while dual-tasking is influenced by factors such as task prioritization and working memory capacity. EEG measurements and pupillometry are promising alternatives. For instance, increased conscious motor control is accompanied by increased coherence between left-lateralised verbal-analytical brain regions (T3-electrode) and central premotor brain regions (Fz).^{68,69,127} Also, it is well known that pupil dilation is positively associated with conscious mental effort.^{330,331} While this has typically been shown in cognitive tasks, we recently found similar results in a whole-body balance task.³³²

A third limitation concerns this thesis' recommendations for a tailored approach to motor learning in rehabilitation after stroke. At the start of this PhD project it was not my primary aim to investigate this issue. While there seems to be a theoretical and empirical basis for my findings (as discussed in section 10.2) results are based on cross-sectional and retrospective analyses. To obtain stronger evidence, it is necessary to investigate whether prospectively allocating patients to a particular intervention based on their characteristics optimizes motor learning (e.g., as per the decision tree in Figure 10.2). Hence, results of this thesis can best be considered as starting points for clinicians and future research into tailored motor learning approaches.

A final limitation concerns the dual-task assessments used in the experimental studies. That is, only one or two types of dual-tasks were used, these being a letter fluency task and/or tone-counting task, respectively. Using a range of different cognitive dual-tasks would have allowed a more comprehensive assessment of dual-tasking ability. On the other hand, a strength of the dual-tasks used is that they all tax patients' executive function. These classes of dual-tasks have been shown to trigger the greatest dual-task interference while moving.³³³

5. Conclusion

This thesis investigated the effects of implicit motor learning through external focus instructions in people with stroke. No evidence was found that implicit motor learning uniformly benefits motor skill, automaticity of movement, and dual-task performance compared to explicit motor learning. It was shown that implicit and explicit motor learning interventions could both be effective, depending on the stroke patients' motor and sensory function, attention capacity, and conscious control inclination. This implies that motor learning should be tailored to the individual patient for optimal effects.

