MOTOR SKILL LEARNING

Age and Augmented Feedback

Henk van Dijk

Address of correspondence:

Henk van Dijk
Roessingh Research and Development BV
PO Box 310
7500 AH Enschede
The Netherlands
+31 53 4875777
h.vandijk@rrd.nl

ISBN 90-365-2302-8

Layout and cover: Ellen Oosterhof, www.ellenoosterhof.nl, Groningen
Printed by Febodruk BV, www.febodruk.nl, Enschede

MOTOR SKILL LEARNING
AGE AND AUGMENTED FEEDBACK

PROEFSCHRIFT

ter verkrijging van
de graad van doctor aan de Universiteit Twente,
op gezag van de rector magnificus,
prof.dr. W. H. M. Zijm,
volgens besluit van het College voor Promoties
in het openbaar te verdedigen
op vrijdag 10 maart 2006 om 13.15 uur

door

Henk van Dijk
geboren op 11 mei 1977
te Oldebroek

Dit proefschrift is goedgekeurd door de promotoren:

Prof.dr.ir. H. J. Hermens
Prof.dr. T. Mulder

De promotiecommissie is als volgt samengesteld:

Voorzitter en secretaris:	
Prof.dr.ir. A. J. Mouthaan	Universiteit Twente
Promotoren:	
Prof.dr.ir. H. J. Hermens	Universiteit Twente
Prof.dr. T. Mulder	Rijksuniversiteit Groningen
Referenten:	
Prof.dr. J. M. Pieters	Universiteit Twente
Leden:	
Prof.dr.ing. W. B. Verwey	Universiteit Twente
Prof.dr.ir. P. H. Veltink	Universiteit Twente
Prof.dr. K. Postema	Rijksuniversiteit Groningen
Prof.dr. M. J. IJzerman	Universiteit Twente
Prof.dr. W. Spijkers	Rheinisch-Westfälische Technische
Hochschule Aachen	

Paranimfen:
Michiel Jannink
Gert Bergman

This study was supported by a grant from the SenterNovem provided to the ExO-Zorg project (project number TSIT1014). SenterNovem is an agency of the Dutch Ministry of Economic Affairs.

The publication of this thesis was generously supported by:
Revalidatiecentrum 'Het Roessingh', Enschede
Roessingh Research and Development, Enschede
Leerstoel Biomedische Signalen and Systemen, Universiteit Twente, Enschede

Contents

CHAPTER 1

Introduction and outline of the thesis

There is a steady increase in age of the population in the western world. In Europe, recent statistics show that approximately 20.7% of the people are over 60 years of age, and it is estimated that this figure will increase to 25.9% by the year 2020[1]. These demographic changes put a substantial pressure on our health care resources because of the growing number of people that need some form of health care[2].

Old age often implies a loss of independence as elderly people find themselves reliant on family and professional caregivers. However, emerging technologies may make it possible for elderly people to remain independent for a longer period of time, with the necessary support that is tailored to their individual needs. In addition, home-based training systems allow people to receive appropriate therapy outside a clinic (see chapter 3: Van Dijk & Hermens[3] for a state of the art on distance training applications). This means that people can go home and continue to work on their recovery without the direct presence of a professional caregiver. Such a system might reduce the burden on health care resources.

The concept of home-based training can be illustrated by a telerehabilitation system developed by Reinkensmeyer et al.[4] for arm and hand therapy following brain injury, termed Java. 'Java therapy' is a Web site with a library of evaluation and therapeutic activities. The activities can be performed with a variety of input devices such as a force feedback joystick. The joystick can physically assist or resist movement as the user performs therapeutic exercises. The system provides augmented feedback of movement performance, allowing users and their caregivers to assess rehabilitation progress. By networking the patient's computer on the Internet, the patient's progress can be recorded and monitored by a therapist while the patient trains from the convenience of his or her own home at an intensity and at a time he or she prefers. The therapist can monitor the progress of the patient without being with the patient in person and can further prescribe different activities for the patient by customizing the Web site based on the needs of the user.

Within this context of emerging technologies, augmented feedback is critical for the successful implementation of such a home-based training application. Here, the professional caregiver is (partly) being replaced by the augmented feedback provided by a certain training device. Augmented feedback has been identified as an important variable that enhances motor learning processes[5-8]. Therefore, the present thesis focuses on the influence of age and augmented feedback on learning motor skills. In the introduction, we will shortly reflect on the definitions and theoretical backgrounds concerning motor skill learning and augmented feedback. The concepts of aging will briefly be discussed. Finally, the main goal of this thesis will be stated, and the outline of the thesis described.

Introduction

The learning and performing of motor skills[a] takes place on a life-long basis. With aging, the ability to learn and relearn skills continues to be crucial for maximizing function and quality of life. For example, older adults may need to learn a new skill such as driving an electric scooter, or they may need to relearn the ability to pick up a coffee cup while recovering from a stroke. Although there is abundance of motor learning research on young adults (see Magill[5]; Proctor & Dutta[6]; Rose & Christina[7]; Schmidt & Lee[8] for an overview), little is known about how older adults learn motor skills. This thesis can be considered as a contribution to this field of motor learning research.

"Motor learning is a set of processes associated with practice or experience leading to relatively permanent changes in the capability for movement"

Schmidt and Lee[8], p. 264.

In the learning of motor skills, motor processes continuously interact with cognitive and sensory processes[9]. The 'quality' of these processes however tends to change when people grow older. Information processing becomes slower (see Salthouse[10]; Welford[11] for a review), which limits the response flexibility of the system[12]. Several studies have reported sensory deficits with advanced age[13,14]. Loss of sensory sensitivity as a result of deterioration of structure and function implies that older adults are impaired in the fast and selective use of information from sensory modalities[15]. In addition, changes in the way elderly people perform movements are found (see Spirduso[16] for an overview).

One of the most critical variables affecting motor skill learning, aside from practice itself, is feedback. Feedback is information arising as a consequence of performance. This information provides a basis for evaluating the correctness of performance[7]. When people perform a skill, they receive two general types of performance-related feedback[4]. One type of feedback is called task-intrinsic (also inherent) feedback, which is the sensory information that is a natural part of performing a skill (e.g. vision, audition, and proprioception). The second type of performance-related feedback is called augmented feedback (also referred to as extrinsic or artificial feedback). The adjective augmented refers to adding to or enhancing task-intrinsic feedback with an external source (e.g. training device).

[a]Motor skills: goal-directed actions or tasks that consist of body / limb movements (Magill[5], p. 3).

Augmented feedback has been the focus of a large body of research (see Mulder & Hulstijn[17]; Newell[18]; Salmoni et al.[19]; Swinnen[20]; Winstein[21] for a review). Most of the research on which we base our present knowledge comes from experiments on young, healthy subjects.

Lee et al.[22] state that augmented feedback is a means of supplementing the sources of task-intrinsic feedback normally available to the learner. The distinction between intrinsic and augmented feedback is however not absolute and is inevitably task dependent[18]. The ability to process task-intrinsic information may be compromised due to age-related changes in information processing or to cognitive / sensory impairments in certain patients groups. In these circumstances, people may be more dependent on augmented feedback to learn motor skills compared to young, healthy people (see chapter 2: Van Dijk et al.[23] for a systematic review on the effect of augmented feedback on motor function in rehabilitation patients).

In optimizing the way in which augmented feedback is presented to the (elderly) learner, the importance of carefully selecting the type of feedback must be emphasized. Substantial work has been conducted in which the effects of feedback variations such as form, content, and timing have been studied on young, healthy subjects[17-21]. Given the decline in cognitive, sensory, and motor processes that accompany aging, there is reason to expect that learning variables such as augmented feedback operate differently in older adults than they do in young adults. The limited evidence available suggests that despite the changes associated with aging, older adults benefit from augmented feedback similarly to young adults[24-27].

The main aim of this thesis is to obtain a better understanding of the influence of **age** and **augmented feedback** on motor skill learning.

Outline of the thesis

A framework is presented in chapter 2 and 3 on how different types of augmented feedback are currently being used in rehabilitation practice. Chapter 2 presents a systematic review in which the goal was to assess the available evidence regarding the effect of augmented feedback on motor function in rehabilitation. Chapter 3 presents a state of the art overview in which promising applications on distance training for the restoration of motor function are reviewed. Chapters 2 and 3 precede the chapters in which the experiments examining the influence of age and augmented feedback in motor skill learning are described. The framework that is created by these two chapters has been used to set up the experiments.

In this thesis, the results of three experiments are described on three different feedback variations, namely **form** (how?), **content** (what?), and **timing** (when?) of feedback. These effects of augmented feedback have been studied in relation to age. This experimental work is presented in the following chapters.

Chapter 4 describes the results of two related studies. The first study was focused on the influence of providing additional information such as augmented feedback on learning a sequential hand-position task. In the second study, the effects of age and the modality of feedback on motor learning using the same sequential task was examined.

Chapter 5 addresses the interaction between age and the informational content of feedback on the acquisition of an isometric force-production task. Subjects were randomly assigned to a certain type of feedback: knowledge of results or kinetic feedback.

Chapter 6 focuses on the influence of the timing of feedback on motor learning. Again, the effect of augmented feedback in relation to age was studied. Performing a gross motor task, subjects had to lower their trapezius muscle activity using the electromyographic signal as myofeedback. Subjects were randomly assigned to two timing conditions of myofeedback: concurrent or terminal myofeedback.

In chapter 7, this thesis concludes with a general discussion of the main findings, together with their implications for motor learning research and rehabilitation practice. Finally, recommendations are made for future research.

References

1. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2004). *World population prospects: the 2004 revision.* Retrieved July 11, 2005, from http://esa.un.org/unpp.
2. Lloyd-Sherlock, P. (2000). Population ageing in developed and developing regions: implications for health policy. *Social Science & Medicine, 51(6),* 887-895.
3. Dijk, H. van, & Hermens, H. J. (2004). Distance training for the restoration of motor function. *Journal of Telemedicine and Telecare, 10(2),* 63-71.
4. Reinkensmeyer, D. J., Pang, C. T., Nessler, J. A., & Painter, C. C. (2002). Web-based telerehabilitation for the upper extremity after stroke. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 10(2),* 102-108.
5. Magill, R. A. (2001). *Motor learning: concepts and applications*. 6th ed. New York: McGraw-Hill.
6. Proctor, R. W., & Dutta, A. (1995). *Skill acquisition and human performance*. Thousand Oaks: Sage.
7. Rose, D. J., & Christina, R. W. (2006). *A multilevel approach to the study of motor control and learning*. 2nd ed. San Francisco: Pearson Education Inc.
8. Schmidt, R. A., & Lee, T. D. (1999). *Motor control and learning: a behavioural emphasis*. 3rd ed. Champaign: Human Kinetics.
9. Mulder, T., & Hochstenbach, J. B. (2003). Motor control and learning: implications for neurological rehabilitation. In R. J. Greenwood (Ed.), *Handbook of neurological rehabilitation* (pp. 143-157). New York: Psychology Press.
10. Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103(3),* 403-428.
11. Welford, A. T. (1984). Between bodily changes and performance: some possible reasons for slowing with age. *Experimental Aging Research, 10(2),* 73-88.
12. Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adults age differences in working memory. *Developmental Psychology, 27,* 763-776.
13. Fozard, J. L., & Gordon-Salant, S. (2001). Changes in vision and hearing with aging. In J. E. Birren, & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 241-266). 5th ed. New York: Academic Press.
14. Seidler, R. D., & Stelmach, G. E. (1995). Reduction in sensorimotor control with age. *Quest, 47(3),* 386-394.
15. Serrien, D. J., Teasdale, N., Bard, C., & Fleury, M. (1996). Age-related differences in the integration of sensory information during the execution of a bimanual coordination task. *Journal of Motor Behavior, 28(4),* 337-347.
16. Spirduso, W. W. (2005). *Physical dimensions of aging*. 2nd ed. Champaign: Human Kinetics.
17. Mulder, T., & Hulstijn, W. (1984). Sensory feedback therapy and theoretical knowledge of motor control and learning. *American Journal of Physical Medicine, 63(5),* 226-244.
18. Newell, K. M. (1991). Motor skill acquisition. *Annual Review of Psychology, 42,* 213-237.
19. Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: a review and critical reappraisal. *Psychological Bulletin, 95(3),* 355-386.
20. Swinnen, S. P. (1996). Information feedback for motor skill learning: a review. In H. N. Zelaznik (Ed.), *Advances in motor learning and control* (pp. 37-66). Champaign: Human Kinetics.
21. Winstein, C. J. (1991). Knowledge of results and motor learning – implications for physical therapy. *Physical Therapy, 71(2),* 140-149.
22. Lee, T. D., Swinnen, S. P., & Serrien, D. J. (1994). Cognitive effort and motor learning. *Quest, 46(3),* 328-344.

23. Dijk, H. van, Jannink, M. J. A., & Hermens, H. J. (2005). Effect of augmented feedback on motor function of the affected upper extremity in rehabilitation patients: a systematic review of randomized controlled trials. *Journal of Rehabilitation Medicine, 37(4)*, 202-211.
24. Carnahan, H., Vandervoort, A. A., & Swanson, L. R. (1996). The influence of summary knowledge of results and aging on motor learning. *Research Quarterly for Exercise and Sport, 67(3)*, 280-287.
25. Swanson, L. R., & Lee, T. D. (1992). Effects of aging and schedules of knowledge of results on motor learning. *Journal of Gerontology: Psychological Sciences, 47(6)*, 406-411.
26. Wiegand, R. L., & Ramella, R. (1983). The effect of practice and temporal location of knowledge of results on the motor performance of older adults. *Journal of Gerontology, 38(6)*, 701-706.
27. Wishart, L. R., & Lee, T. D. (1997). Effects of aging and reduced relative frequency of knowledge of results on learning a motor skill. *Perceptual and Motor Skills, 84(3Pt1)*, 1107-1122.

CHAPTER 2

Effect of augmented feedback on motor function of the affected upper extremity in rehabilitation patients: a systematic review of randomized controlled trials

H. van Dijk, M. J. A. Jannink, and H. J. Hermens

Journal of Rehabilitation Medicine 2005, 37(4), 202-211

Abstract

Objective: Assessment of the available evidence regarding the effect of augmented feedback on motor function of the upper extremity in rehabilitation patients.

Methods: A systematic literature search was performed to identify randomized controlled trials that evaluated the effect of augmented feedback on motor function. Two reviewers systematically assessed the methodological quality of the trials. The reported effects were examined to evaluate the effect of therapeutic interventions using augmented feedback and to identify a possible relationship with patient characteristics, type of intervention, or methodological quality.

Results: Twenty-six randomized controlled trials were included, nine of which reported a positive effect on arm function tests. Follow-up measurements were performed in eight trials, one of which reported a positive effect. Different therapeutic interventions using augmented feedback, i.e. electromyographic biofeedback, kinetic feedback, kinematic feedback, and knowledge of results, show no difference in effectiveness.

Conclusion: No firm evidence is found of effectiveness regarding the use of augmented feedback to improve motor function of the upper extremity in rehabilitation patients. Future studies should focus more attention to the content, form, and timing of augmented feedback concerning the therapeutic intervention. It should be emphasized that motor learning effects can only be determined by re-examining the population after a follow-up period.

Introduction

Feedback, along with practice, is considered to be a potent variable affecting motor skill learning[1,2]. When one performs a task, there are two general types of performance-related information, or feedback, available. One type of feedback is called task-intrinsic (or inherent) feedback, which is the sensory-perceptual information that is a natural part of performing a skill. For example, a person sees that he has missed picking up a cup with his hands. The second type of feedback is called augmented feedback. Although various terms have been used to identify this type of feedback (information, extrinsic, or artificial feedback), the term that will be used in this review is augmented feedback. Augmented refers to adding to or enhancing task-intrinsic feedback with an external source[2,3]. The external source may be a training device such as a biofeedback system. This review focuses on the influence of augmented feedback on the performance and learning of motor skills.

Augmented feedback has been the focus of a large body of research (see Salmoni et al.[4]; Winstein[5] for a review) and provides a fundamental cornerstone for motor learning theories. Substantial work has been conducted in which the effects of feedback variations such as content, form, and timing have been studied[2,3]. Most of the research on which we base our knowledge of augmented feedback comes from laboratory experiments in which researchers gave augmented feedback to young, healthy participants. Typical tasks involved in these studies were simple and very contrived.

Augmented feedback, properly employed, may have practical implications for rehabilitation therapy since the re-acquisition of motor skills is an important part of functional motor recovery[5,6]. Some patients with cognitive and perceptual impairments are not able to use intrinsic feedback to guide their performance[7]. Furthermore, because their own abilities to generate intrinsic feedback may be compromised by neurological sensory impairments, they may be more dependent on augmented feedback[8]. However, a rehabilitation professional may find it difficult to implement the motor learning principles due to problems with generalizing the laboratory-based motor learning studies into a clinical setting[9].

Within the rehabilitation setting, therapeutic interventions are often aimed at improving motor function of the upper extremity. For example, loss of function of the affected upper extremity is a major problem after stroke[10]. Also, patients with Parkinson's disease experience persistent difficulties with motor function of the upper extremity[11].

In recent decades, a number of articles have been published in which the effect of various rehabilitation methods using augmented feedback to improve arm function has been evaluated. Apart from many clinical studies of varying designs, several attempts have been made to synthesize the findings in reviews and meta-analyses. Most of these focus on one specific therapeutic intervention such as EMG biofeedback[12-14]. However, the present review focused on the augmented feedback underlying a diversity of therapeutic interventions.

This present systematic review was performed to address the following research questions:

- What is the effect of therapeutic interventions using augmented feedback on motor function of the affected upper extremity in rehabilitation patients?
- Is there a relationship between the reported effects and patient characteristics, type of intervention, or methodological quality?

Methods

Computerized literature searches were performed using MEDLINE (1966 – December 2004), EMBASE (1974 – December 2004), and Cochrane Controlled Trials Register (Cochrane Library Issue 1, 2004). The specialist rehabilitation research databases CIRRIE (Center for International Rehabilitation Research Information and Exchange; 1990 – December 2004) and REHABDATA (1956 – December 2004) were also searched. The CIRRIE database contains citations of international rehabilitation research. REHABDATA is an extensive database of disability and rehabilitation literature abstracts. The following key words were used: feedback, biofeedback, knowledge of results, reinforcement, cues, knowledge of performance, upper extremity, arm, upper limb, and rehabilitation. The MEDLINE search strategy is outlined in Appendix 1. In addition, references to relevant publications were hand-searched.

Two reviewers (HvD and MJAJ) screened the titles and abstracts of the results of the literature searches independently. Trials that met the following criteria were included in the review:

- Therapeutic intervention applied to improve the motor function of the affected upper extremity in rehabilitation patients.
- Therapeutic intervention using augmented feedback.
- Outcomes measured at impairment / disability level.
- Randomized controlled trial (RCT).
- Published, full-length publication.

This systematic review only included RCTs because these are considered to have the most robust study design with the least risk of biased results. The reviewers did not apply any language restriction.

The publications that appeared to meet the inclusion criteria were retrieved and full-length publications were reviewed in further detail. In a consensus meeting, the two reviewers made the final decision on whether or not a publication should be included in the final review. In cases of disagreement, consensus was reached by discussion or, if necessary, by consulting a third reviewer (HJH).

The methodological quality of each included trial was assessed. A standardized quality scoring form (the Delphi list) containing nine criteria was used to assess the randomization, treatment allocation, comparability between groups, eligibility criteria, blinding (of outcome assessor, care provider and patient), point estimates and measures of variability, and intention-to-treat analysis (see Appendix 2)[15]. The nine criteria could be rated as 'do not know' if the available information was unclear or insufficient. If the available information was sufficiently clear, criteria were rated as 'yes', indicating adequate methods, or 'no', indicating inadequate methods or potential bias. Each 'yes' was scored as one point, and therefore, a maximum of nine points was possible.

The two reviewers (HvD and MJAJ) independently extracted data (methodological quality criteria, patient characteristics, type of intervention, outcome measures, and reported effects in the original publications) using a structured form. Blinding of the reviewers was not considered feasible because both reviewers already had considerable knowledge of the literature included in the review. Any differences of opinion were resolved by discussion or by the assistance of the third reviewer (HJH). Tables describing the included trials were generated. If necessary, trialists were contacted and requested to supply missing data. Concerning the therapeutic intervention, four different types of augmented feedback were reported: biofeedback, kinetic feedback, kinematic feedback, and knowledge of results. The term biofeedback refers to an augmented form of feedback related to the activity of physiological processes within the body such as muscle activity (electromyographic (EMG) biofeedback)[2,3]. A detailed description of the movement pattern or response dynamics requires kinetic / kinematic feedback. Kinetic feedback parameters are obtained from the units of mass, force, and time and often include impulse and peak force measures. Kinematic feedback parameters are derived from the dimensions of length and time and common kinematic parameters include displacement, velocity, and acceleration values[16]. Knowledge of results (KR) is a score presented to the performer as a representation of the outcome of the movement[2-4]. This score often represented the error discrepancy between the performer's obtained response and some externally defined goal, although it can also be a representation of the actual outcome obtained.

The result of each trial was summarized as either '+' (positive for the experimental group, $p \leq .05$) or '0' (no difference, $p \geq .05$), according to the results presented in the original publications. In case of more than one reported effect (e.g. the experimental intervention consists of more than 1 group) the reviewers selected the most relevant comparison of groups according to the research question. An attempt was made to identify a relationship between reported effects and the following variables: patient characteristics (different diagnoses), type of intervention (different types of augmented feedback), and two methodological characteristics that have been shown to cause bias in the results of earlier reviews (concealed allocation of treatment and blinding of the outcome assessor)[17,18].

Results

The systematic search of the literature resulted in the identification of 33 publications, 27 of which fulfilled the selection criteria and were included in the present review[19-45]. Six publications were excluded because these trials were not randomized. (A list of the excluded articles can be obtained on request from the first author.) In the 27 publications included in the review, 26 RCTs were described. The study characteristics and the methodological scores rated by the present reviewers are presented in Table 1.

Table 1. Characteristics of included RCTs and methodological scores

Reference	**Patients**	**Diagnosis**	**Age M (SD)**		**Time post-onset M (SD)**	
			E group	C group	E group	C group
Armagan[19]	14E / 13C	Stroke	57.0 yr (10.5)	57.9 yr (11.3)	4.4 mo (1.1)	4.8 mo (1.3)
Basmaijan[20]	Total n=37; ?E / ?C	Stroke	65 yr (40-79)	62 yr (48-74)	3.5 mo (2-6)	2.8 mo (2-5.5)
Basmaijan[21]	13E / 16C	Stroke	60.8 yr (8.5)	63.8 yr (13.1)	16.4 wk (7.6)	16.0 wk (11.7)
Bourbonnais[22]	13E / 12C	Stroke	47.2 yr (13.9)	44.6 yr (14.1)	37.3 mo (14.3)	34.7 mo (16.1)
Bowman[23]	15E / 15C	Stroke	?	?	Total: 3 wk-4 mo	
Croce[24]	14E[1] / 13E[2] / 12E[3] / 12C	TBI	Total: 29.2 yr (8.2)		Total: 21.2 d (10.6)	
Crow[25]	20E / 20C	Stroke	67.4 yr (10.5)	68.1 yr (9.5)	Total: 2-8 wk	
Greenberg[26]	10E / 10C	Stroke	63.3 yr (14.9)	66.5 yr (4.2)	3.3 yr (2.1)	3.0 yr (1.5)
Hurd[27]	12E / 12C[1] / 20C[2]	Stroke	59.4 yr (18.3)	C[1]: 55.8 yr (19.1) / C[2]: 54.8 yr (18.6)	74.5 d (54.5)	C[1]: 79.3 d (57.8) / C[2]: 60.2 (42.8)
Inglis[28]	15E / 15C; partial crossover design	Stroke	59.6 yr (7.3)	61.9 yr (8.3)	22.8 mo (23.2)	14.4 mo (14.1)

Intervention – duration		**Outcome measures**[a]	**Methodological score**
E group	C group		
EMG biofeedback and conventional therapy - 5 sessions of 20 min a wk for 4 wk	Placebo EMG biofeedback and conventional therapy - 5 sessions of 20 min a wk for 4 wk	Active ROM; Brunnstrom's stages of recovery; drinking from a glass; EMG activity	7
Integrated behavioral and physical therapy (including EMG biofeedback) - 3 sessions of 40 min a wk for 5 wk	Conventional therapy - 3 sessions of 40 min a wk for 5 wk	UEFS; Minnesota rate of manipulation test; 9 hole peg test; Ontario society of occupational therapists test; grip and pinch	5
Integrated behavioral and physical therapy (including EMG biofeedback) - 3 sessions of 45 min a wk for 5 wk	Conventional therapy - 3 sessions of 45 min a wk for 5 wk	UEFS; finger oscillation test	5
Force feedback – 3 sessions a wk for 6 wk	No treatment	TEMPA; BBT; finger-to-nose test; shoulder and elbow strength; handgrip strength; FM; spasticity	4
Positional feedback stimulation training and conventional therapy - 2 sessions of 30 min a wkd for 4 wk (+ conventional therapy)	Conventional therapy - 5 d a wk for 4 wk	Active ROM; wrist extension torque	4
E^1: KR on every trial; E^2: summary KR; E^3: average KR - 60 trials	No KR - 60 trials	Absolute constant error; variable error	3
EMG biofeedback and conventional therapy - 6 wk	Placebo EMG biofeedback and conventional therapy - 6 wk	Action research arm test; FM	6
Kinesthetic biofeedback - 2 sessions of 30 min a wk for 4 wk	Conventional therapy - 2 sessions of 30 min a wk for 4 wk	Active elbow extension	4
EMG biofeedback and conventional therapy - ? sessions of 20 min for 2 wk (+ conventional therapy)	C^1: simulated EMG biofeedback and conventional therapy - ? sessions of 20 min for 2 wk (+ conventional therapy); C^2: conventional therapy - 2 wk	Active ROM; passive ROM; EMG activity	6
EMG biofeedback and conventional therapy - 20 sessions (4 blocks of 5)	Conventional therapy - 20 sessions (4 blocks of 5)	Active ROM; strength of muscle activity; picture goniometry; Brunnstrom's stages of recovery	4

Table 1. Continued

Reference	**Patients**	**Diagnosis**	**Age M (SD)**		**Time post-onset M (SD)**	
			E group	C group	E group	C group
Klose[29]	14E / 14C	SCI	26.4 yr (5.3)	24.3 yr (4.0)	Total: at least 1 yr	
Klose[30]	$10E^1$ / $10E^2$ / $9E^3$ / 10C	SCI	Total: ? (18-45)		Total: at least 1 yr	
Kohlmeyer[31]	$13E^1$ / $10E^2$ / $11E^3$ / 10C	SCI	E^1: 38 yr (15) / E^2: 32 yr (18) / E^3: 42 yr (15)	43 yr (18)	E^1: 2.8 wk (1.0) / E^2: 3.2 (0.9) / E^3: 2.5 (1.0)	3.0 wk (0.9)
Lee[32]	18E / $18C^1$ / $18C^2$; crossover design	Stroke	64 yr (?)	C1: 44 yr (?) / C2: ? Total: 56.6 yr (31-79)	Total: 6 wk-7 yr	
Lum[33]	13E / 14C	Stroke	63.2 yr (3.6)	65.9 yr (2.4)	30.2 mo (6.2)	28.8 mo (6.3)
Marchese[34]	10E / 10C	PD	65.0 yr (5.8)	66.9 yr (6.3)	Total: 28-168 mo	
Mroczek[35]	9E / 9C; crossover design	Stroke	Total: ? (50-75)		Total: 1-10 yr	
Platz[36]	$7E^1$ / $8E^2$ / $7C^1$ / $8C^2$	PD	E^1 65.9 yr (8.3) / E^2: 62.0 yr (14.6)	C^1: 62.1 yr (13.3) / C^2: 60.8 yr (15.2)	E^1: 7.6 yr (2.6) / E^2:4.3 (1.8)	Healthy subjects as controls
Platz[37]	$20E^1$ / $20E^2$ / 20C	Stroke and TBI	E^1: 49 yr (17.9) / E^2: 54 yr (18.0)	58.0 yr (15.3)	E^1: 6.1 wk (3.6) / E^2: 6.2 (7.1)	10.3 wk (19.9)

Intervention – duration		**Outcome measures[a]**	**Methodological score**
E group	C group		
EMG biofeedback, neuromuscular stimulation, and conventional therapy - 3 sessions of 1 h and 15 min a wk for 12 wk	Conventional therapy and neuromuscular stimulation - 3 sessions of 45 min a wk for 12 wk	Functional abilities measure; manual muscle test	4
E^1: EMG biofeedback and conventional therapy; E^2: EMG biofeedback and neuromuscular stimulation; E^3: neuromuscular stimulation and conventional therapy - 3 d a wk for 16 wk	Conventional therapy - 3 d a wk for 16 wk	Self-care score; mobility score; manual muscle test; EMG activity	4
E^1: EMG biofeedback; E^2: functional electrical stimulation; E^3: EMG biofeedback and functional electrical stimulation - 5 sessions of 20 min a wk for 5-6 wk	Conventional therapy - 5 sessions of 20 min a wk for 5-6 wk	Function score evaluation; manual muscle test	4
EMG biofeedback - 20 contractions of 5 s	C1: placebo EMG biofeedback; C2: conventional therapy - 20 contractions of 5 s	EMG activity	3
Robot-assisted movement training - 24 sessions of 1 h over 2-mo period	Conventional therapy - 24 sessions of 1 h over 2-mo period	FIM™ (self-care and transfer sections); BI; FM; shoulder and elbow strength; reaching ability	5
Cued physical therapy - 3 sessions of 1 h a wk for 6 wk	Non-cued physical therapy - 3 sessions of 1 h a wk for 6 wk	UPDRS	5
EMG biofeedback - 3 sessions of 30 min a wk for 4 wk	Conventional therapy - 3 sessions of 30 min a wk for 4 wk	Active ROM; EMG activity	3
E^1: KR auditory rhythmic cues; E^2: KR without auditory rhythmic cues - 100 trials	C^1: KR with auditory rhythmic cues; C^2: KR without auditory rhythmic cues - 100 trials	End-point accuracy; total movement time; movement duration; maximum tangential acceleration; maximum deceleration	4
E^1: arm ability training and conventional therapy; E^2: KR, arm ability training, and conventional therapy - 32 min a wkd for 3 wk (+ conventional therapy)	Conventional therapy - ?	TEMPA; kinetically analysis of aiming movements	6

Table 1. Continued

Reference	**Patients**	**Diagnosis**	**Age M (SD)**		**Time post-onset M (SD)**	
			E group	C group	E group	C group
Shumaker[38]	10E / 10C	PD	65.2 yr (?)	67.2 yr (?)	10.7 yr (?)	12.6 yr (?)
Smith[39]	6E / 5C	Stroke	55.5 yr (40-67)	48.6 yr (22-67)	23.0 mo (7-69)	12.8 mo (6-30)
Sunderland[41,40]	36E[1] / 29E[2] / 35C[1] / 32C[2]	Stroke	E[1]: 65 yr (32-88) / E[2]: 67 yr (46-92)	C[1]: 68 yr (50-82) / C[2]: 70 yr (35-84)	E[1]: 8 d (2-35) / E[2]: 9 (1-31)	C[1]:10 d (2-31) / C[2]: 8 (0-29)
Talbot[42]	20E / 19C[1] / 20C[2]	CP	Total: 14 yr 3 mo (7-21)		?	
Williams[43]	10E[1] / 10E[2]; cross-over design	Stroke	Total: 63.5 yr (11.8)		Total: 3-16 wk	
Wolf[44]	8E / 8C	Stroke	63.9 yr (10.9)	62.0 yr (14.4)	32.6 mo (16.4)	65.5 mo (39.5)
Wolf[45]	14E / 12C	Stroke and TBI	54.7 yr (20.3)	46.0 yr (17.3)	Total: 1-7 yr	

Intervention – duration		Outcome measures[a]	Methodological score
E group	C group		
Frontal EMG biofeedback and progressive relaxation training - 1 session a wk for 15 wk	No treatment	General aptitude test battery (parts 9 placing test and 10 turning test)	4
EMG biofeedback - 2 sessions of 1 h a wk for 6 wk	Conventional therapy - 2 sessions of 1 h a wk for 6 wk	Brunnstrom's stages of recovery; audio-visual films	3
E^1: enhanced physical therapy (including EMG biofeedback) - severe group; E^2: mild group - median of 7 wk (0-33) of inpatient therapy; median of 11 wk (0-50) of outpatient therapy	C^1: conventional therapy - severe group; C^2: mild group - median of 4 wk (0-48) of inpatient therapy; median of 6 wk (0-45) of outpatient therapy	BI; Frenchay arm test; 9 hole peg test; EMI; subtests of the motor club assessment; sensory loss; passive movement and pain	6
Tracing with auditorally augmented feedback - 2 sessions of 10 min a d; a total of 40	C^1: tracing alone - 2 sessions of 10 min a d; a total of 40 sessions; C^2: no tracing, no feedback	SCMAT	4
E^1: EMG biofeedback and conventional therapy - 5 d of 20-25 min treatment (+ conventional therapy of 1 h); E^2: relaxation therapy and conventional therapy - 2 d of 30 min instruction (+ conventional therapy of 1 h)	-	McGill Pain questionnaire (parts I to IV); passive ROM	5
EMG biofeedback - 10 sessions of 25 min	Conventional movement training - 10 sessions of 25 min	Movement speed; active and passive ROM; EMG activity	4
Motor copy (EMG biofeedback) - sequence of 30 treatments	Conventional targeting training (EMG biofeedback) - sequence of 30 treatments	Active ROM; functional tasks based on force or time measures; EMG activity	4

[a]Outcome measures not concerning the upper extremity were omitted.

Abbreviations:
E, experimental; C, control; SD, standard deviation; ROM, range of motion; PD, Parkinson's disease; SCI, spinal cord injury; TBI, traumatic brain injury; CP, cerebral palsy; EMG, electromyographic; KR, knowledge of results; UEFS, upper extremity functional scale; TEMPA, Test Évaluant la Performance des Membres supérieurs des Personnes Âgées; BBT, box-and-blocks test; FM, Fugl-Meyer assessment; FIM, functional independence measure; BI, Barthel index; UPDRS, unified Parkinson's disease rating scale; EMI, extended motricity index; SCMAT, southern California motor accuracy test; M, mean; SD, standard deviation; yr, year(s); mo, month(s); week, wk; wkd, weekday; d, day(s); h, hour(s); min, minute(s); s, second(s)

The number of patients included in a trial ranged from nine[35] to 132[40,41]. In 18 trials[19-23,25-28,32,33,35,37,39-41,43-45], the study population concerned stroke patients. Other study populations were patients with traumatic brain injury (TBI)[24,37,45], spinal cord injury (SCI)[29-31], Parkinson's disease (PD)[34,36,38] and cerebral palsy (CP)[42]. Platz et al.[36] used healthy subjects as controls.

The type of therapeutic intervention varied between trials. Effects of EMG biofeedback[19-21,25,27-32,35,38-41,43-45], kinetic feedback[22,33], kinematic feedback[23,26], and KR[24,34,36,37,42] were described. In four trials, electrical stimulation (ES) was used to support the therapeutic intervention using augmented feedback; three were in addition to the EMG biofeedback[29-31]; one in addition to kinematic feedback[23]. In four trials[19,25,27,32], the experimental intervention EMG biofeedback was simulated by offering the control group placebo EMG biofeedback.

In most trials, two or more different outcome measures were applied (Table 1). Five trials[26,32,34,38,42] only used one outcome measure (relevant for the upper extremity) to determine the effect of the experimental intervention. The most frequently used outcome measures were active[19,23,27,28,35,44,45] / passive[27,43,44] range of motion (ROM – 10 times) and EMG activity (7 times)[19,27,30,32,35,44,45]. It was not always clear what the primary outcome measure was.

There was a disagreement between the two reviewers on 13 out of 234 (5.6%) of the items assessing the methodological quality. Consensus on these items was reached by discussion between the two reviewers, so the third reviewer was not consulted. The scores for methodological quality ranged from three[24,32,35,39] to seven[19] out of nine possible points. In all trials, a method of randomization was performed (although concealed allocation was only reported in 3 trials)[19,37,40,41] and the eligibility criteria were specified. Groups were not similar (or the available information was unclear or insufficient) at baseline in six trials[22-24,32,35,39]. The outcome assessor was not blinded in 11 trials[22,24,26,29,32,35,36,38,42,44,45]. In none of the trials was the care provider blinded. The blinding of patients was performed in four trials with the use of simulated / placebo EMG biofeedback[19,25,27,33]. Point estimates and measures of variability were not presented for the primary outcome measures in six trials[23,28,30-32,39]. None of the trials described an intention-to-treat analysis.

The relationship between four study characteristics and reported effects (either summarized as '+' or '0') on motor function of the upper extremity is presented in Table 2. These study characteristics are patient characteristics, type of intervention, and the methodological characteristics concealed allocation of treatment and blinding of the outcome assessor. In four trials of the 26 RCTs, the obtained effects were not reported because no (relevant) statistical test was applied[24,39] or the augmented feedback was used in both experimental and control group[36,45]. Follow-up measurements were performed in eight trials[21,22,25,33,34,37,40-42].

Additionally in Table 2, the contrast in duration of the exercise treatments was presented. In seven trials[22,23,27,29,38,40,41,43], there was a contrast in the duration of the exercise treatment between the experimental (E) and received control (C) intervention for the most relevant comparison of groups. In three of these seven trials[23,27,40,41], the reported result was positive in favor of the more intensive treatment. In six trials out of 15[19,25,28,33,34,42] without such a contrast in the duration of treatment, a positive effect for the therapeutic intervention was reported. Table 2 shows there is no relationship between the reported effects and patient characteristics or type of intervention. Based on the distribution of the 22 RCTs according to the methodological criteria of concealment allocation and blinding the outcome assessor, there is no reason to suspect that the results were biased.

Table 2. Relationship between reported effects of the augmented feedback on arm function and study characteristics

Reference	Reported effect[a]	Contrast in duration of treatment[b]	Patient characteris-tics	Type of intervention	Conceal-ment of allocation[b]	Blinding of outcome assessor[b]
Shumaker[38]	0	+	PD	EMG biofeedback	-	-
Klose[29]	0	+	SCI	EMG biofeedback	-	-
Klose et al[c 30]	0	-	SCI	EMG biofeedback	-	+
Kohlmeyer[d 31]	0	-	SCI	EMG biofeedback	-	+
Basmaijan[20]	0	-	Stroke	EMG biofeedback	-	+
Basmaijan[21]	PT 0 FU 0	-	Stroke	EMG biofeedback	-	+
Lee[32]	0	-	Stroke	EMG biofeedback	-	-
Mroczek[35]	0	-	Stroke	EMG biofeedback	-	-
Williams[e 43]	0	+	Stroke	EMG biofeedback	-	+
Wolf[44]	0	-	Stroke	EMG biofeedback	-	-
Bourbonnais[22]	PT 0 FU 0	+	Stroke	Kinetic feedback	-	-
Greenberg[26]	0	-	Stroke	Kinematic feedback	-	-
Platz[e 37]	PT 0 FU 0	-	Stroke, TBI	KR	+	+
Armagan[19]	+	-	Stroke	EMG biofeedback	+	+
Hurd[f 27]	+	+	Stroke	EMG biofeedback	-	+
Inglis[28]	+	-	Stroke	EMG biofeedback	-	+
Sunderland[41,40]	PT + FU 0	+	Stroke	EMG biofeedback	+	+
Crow[25]	PT + FU 0	-	Stroke	EMG biofeedback	-	+
Lum[33]	PT + FU 0	-	Stroke	Kinetic feedback	-	+
Bowman[23]	+	+	Stroke	Kinematic feedback	-	+
Talbot[g 42]	PT + FU 0	-	CP	KR	-	-
Marchese[34]	PT 0 FU +	-	PD	KR	-	+

[a]Effect reported in original publication on outcome measure selected as primary by the authors / reviewers; PT, post-test; FU, follow-up. [b]'+' means yes; '-' means 'no' / 'do not know'. [c]E^1 and E^2 compared to C. [d]E^1 and E^3 compared to C. [e]E^1 compared to E^2. [f]E compared to C^2. [g]E compared to C^1.

Abbreviations:
PD, Parkinson's disease; SCI, spinal cord injury; TBI, traumatic brain injury; CP, cerebral palsy; EMG, electromyographic; KR, knowledge of results

Discussion

In this systematic review, the results of 26 RCTs were analyzed in order to assess the effect of therapeutic interventions using augmented feedback on motor function of the affected upper extremity in rehabilitation patients and to identify a possible relationship between the reported effects and patient characteristics (different diagnoses), type of intervention (different types of augmented feedback), or methodological quality.

With regard to the first research question, the findings of this systematic review do not enable a definitive conclusion to be drawn about the effectiveness of therapeutic interventions using augmented feedback to improve upper extremity function in rehabilitation patients. Nine RCTs[19,23,25,27,28,33,34,40-42] showed a positive (short-term or long-term) effect between treatment groups in favor of the applied intervention using augmented feedback and 13 RCTs[20-22,26,29-32,35,37,38,43,44] showed no difference between the applied interventions.

Several forms of bias could have influenced the results of the various trials, indicating that the results should be interpreted with caution. Firstly, a contrast in the duration of the exercise treatment is known to bias the results in favor of the more intensive treatment[46]. There was a contrast in the duration of the treatment in seven trials[22,23,27,29,38,40,41,43], three of which[23,27,40,41] reported a positive effect. This positive result is attributed to augmented feedback, but it might also be the result of longer duration of the treatment. Secondly, the results of this review might be biased due to the incompleteness of the intervention characteristics. Although the reviewers explicitly tried to extract this data using a structured form, the form, content, and timing of the augmented feedback concerning the different types of intervention could often not be explored due to insufficient reported information. Motor learning research has proven that these factors have great influence on the performance and learning of motor skills[2,3].

Motor skill learning can be defined as a set of internal processes associated with practice or experience leading to a relatively permanent change in the capability for movement[2,3,5]. This rules out the changes in motor skills that can come from a variety of temporary performance factors. It is therefore remarkable about the presented trials that only eight RCTs[21,22,25,33,34,37,40-42] performed a follow-up measurement to determine if the improvement in motor function of the upper extremity lasted after a period of non-therapy. Of these eight, only the study of Marchese et al.[34] showed a positive motor learning effect, i.e. a relatively permanent effect after a period of non-therapy, of the experimental intervention (using KR) in comparison with the control group. In this study, the clinical improvements in the 'non-cued' group had faded at six weeks post-treatment, while in the experimental 'cued' group the improvements still endured. Four of the eight RCTs[25,33,41,42] showed a lack of persistence of the gained difference between the treatment groups. This might be caused by short, low-intensity treatment periods. For a therapeutic intervention to be fully effective, the treatment / therapy has to be of sufficient duration and intensity[46].

With regard to the second research question, no firm relationship could be identified between the reported effects and patient characteristics or type of intervention. Identification of groups of patients, who might be more likely to benefit from a specific type of intervention, was difficult because of the heterogeneity of the trials. Different types of interventions using augmented feedback, i.e. EMG biofeedback, kinetic feedback, kinematic feedback, or KR, have shown no difference in effectiveness.

Meta-analysis is a statistical technique for increasing the power of the clinical outcome data by pooling individual trial outcomes[47]. It was not possible to perform a meta-analysis of the findings of different RCTs resulting in a single summary effect size. The selected trials were too heterogeneous with regard to patient characteristics and type of intervention. It was therefore decided to refrain from performing a pooled analysis in this review. Moreover, the focus of the present review was on the augmented feedback underlying the therapeutic intervention. The heterogeneity of the included trials was expected as the inclusion criteria did not focus on patient diagnosis or therapeutic intervention. Concerning the specific therapeutic intervention EMG biofeedback, three meta-analyses are available that assessed the efficacy of biofeedback therapy in post-stroke rehabilitation[12-14].

Regarding the methodological quality of the included RCTs in relation to the reported effects, it is noticeable that the methodological score (rated by the 2 reviewers) is slightly higher for the trials reporting a positive effect in favor of the experimental treatment in comparison to the trials reporting a negative effect, i.e. mean score of 5.2 for trials reporting a positive effect and 4.2 for trials reporting a negative effect. This higher score is largely attributable to the blinding of the outcome assessor (Table 2). One might expect that blinding the outcome assessor decrease the opportunity for a positive effect to occur since the assessor is likely to favor the experimental treatment. This is however not the case in the present review. The authors did not find an explanation for this.

The methodological scores are generally low (a score of 3 or 4 out of 9) for the majority of the included trials (15 trials out of the total of 26 trials). Future studies should more consider the concealment of treatment allocation, the blinding of care providers and patients, and an intention-to-treat analysis as design requirements.

Although augmented feedback is widely regarded as a critical variable in the (re-)acquisition of motor skills, no firm evidence is found of the effectiveness of the use of augmented feedback to improve arm function in rehabilitation patients in the present review. This does not imply evidence of no effect. Winstein[5] suggested that it is appropriate to use the principles of motor learning obtained through laboratory experimentation as guidelines when applying basic research findings to clinical practice. However, given the insufficient reported information in the included publications, it is not yet possible to formulate to what extent these principles of motor learning (regarding the use of augmented feedback) are properly employed. Future studies should focus more on the form, content, and timing of the augmented feedback in order to clarify its importance. Also, more studies should recognize the difference between performance and learning effects concerning the (re-)acquisition of motor skills by re-examining the study population after a follow-up period.

Appendix 1

MEDLINE search strategy

1. Feedback [MeSH]
2. Biofeedback [MeSH]
3. Knowledge of results [MeSH]
4. Reinforcement [MeSH]
5. Cues [MeSH]
6. Knowledge [tw] AND Performance [tw]
7. Upper extremity [MeSH]
8. Arm [MeSH]
9. Upper limb [tw]
10. Rehabilitation [MeSH]
11. #1 OR #2 OR #3 OR #4 OR #5 OR #6
12. #7 OR #8 OR #9
13. #10 AND #11 AND #12 AND Randomized controlled trial [pt]
14. #13 AND Human [MeSH]

Appendix 2

The Delphi list

1. Was a method of randomization performed?
2. Was the treatment allocation concealed?
3. Were the groups similar at baseline regarding the most important prognostic indicators?
4. Were eligibility criteria specified?
5. Was the outcome assessor blinded?
6. Was the care provider blinded?
7. Was the patient blinded?
8. Were point estimates and measures of variability presented for the primary outcome measures?
9. Did the analysis include an intention-to-treat analysis?

References

1. Newell, K. M. (1991). Motor skill acquisition. *Annual Review of Psychology, 42,* 213–237.
2. Schmidt, R. A., & Lee, T. D. (1999). *Motor control and learning: a behavioural emphasis*. 3rd ed. Champaign: Human Kinetics.
3. Magill, R. A. (2001). *Motor learning: concepts and applications*. 6th ed. New York: McGraw-Hill.
4. Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: a review and critical reappraisal. *Psychological Bulletin, 95(3),* 355-386.
5. Winstein, C. J. (1991). Knowledge of results and motor learning – implications for physical therapy. *Physical Therapy, 71(2),* 140-149.
6. Kilduski, N. C., & Rice, M. S. (2003). Qualitative and quantitative knowledge of results: effects on motor learning. *American Journal of Occupational Therapy, 57(3),* 329–336.
7. Flinn, N. A., & Radomski, M. V. (2002). Learning. In C. A. Trombly, & M. V. Radomksi (Eds.), *Occupational therapy for physical dysfunction* (pp. 283-297). 5th ed. Baltimore: Lippincott Williams & Wilkins.
8. Sabari, J. S. (2001). Teaching activities in occupational therapy. In L. W. Pedretti, & M. B. Early (Eds.), *Occupational therapy: practice skill for physical dysfunction* (pp. 83-90). 5th ed. Philadelphia: Mosby.
9. Giuffrida, C. G. (1998). Motor learning: an emerging frame of reference for occupational performance. In M. E. Neistadt, & E. B. Crepeau (Eds.), *Willard & Spackman's occupational therapy* (pp. 65-75). 9th ed. Philadelphia: Lippincott.
10. Broeks, J. G., Lankhorst, G. J., Rumping, K., & Prevo, A. J. (1999). The long-term outcome of arm function after stroke: results of a follow-up study. *Disability and Rehabilitation, 21(8),* 357–364.
11. Dural, A., Atay, M. B., Akbostanci, C., & Kucukdeveci, A. (2003). Impairment, disability, and life satisfaction in Parkinson's disease. *Disability and Rehabilitation, 25(7),* 318–323.
12. Glanz, M., Klawansky, S., Stason, W., Berkey, C., Shah, N., Phan, H. et al. (1995). Biofeedback therapy in poststroke rehabilitation: a meta-analysis of the randomized controlled trials. *Archives of Physical Medicine and Rehabilitation, 76(6),* 508-515.
13. Moreland, J., & Thomson, M. A. (1994). Efficacy of electromyographic biofeedback compared with conventional physical therapy for upper-extremity function in patients following stroke: a research overview and meta-analysis. *Physical Therapy, 74(6),* 534-547.
14. Schleenbaker, R. E., & Mainous, A. G. 3rd (1993). Electromyographic biofeedback for neuromuscular reeducation in the hemiplegic stroke patient: a meta-analysis. *Archives of Physical Medicine and Rehabilitation, 74(12),* 1301–1304.
15. Verhagen, A. P., Vet, H. C. de, Bie, R. A. de, Kessels, A. G., Boers, M., Bouter, L. M. et al. (1998). The Delphi list: a criteria list for quality assessment of randomized clinical trials for conducting systematic reviews developed by Delphi consensus. *Journal of Clinical Epidemiology, 51(12),* 1235–1241.
16. Newell, K. M., & Walter, C. B. (1981). Kinematic and kinetic parameters as information feedback in motor skill acquisition. *Journal of Human Movement Studies, 7,* 235–254.
17. Chalmers, T. C., Celano, P., Sacks, H. S., & Smith, H. (1983). Bias in treatment assignment in controlled clinical trials. *The New England Journal of Medicine, 309(22),* 1358–1361.
18. Moher, D., Pham, B., Jones, A., Cook, D. J., Jadad, A. R., Moher, M. et al. (1998). Does quality of reports of randomised trials affect estimates of intervention efficacy reported in meta-analysis? *Lancet, 352(9128),* 609-613.

19. Armagan, O., Tascioglu, F., & Oner, C. (2003). Electromyographic biofeedback in the treatment of the hemiplegic hand: a placebo-controlled study. *American Journal of Physical Medicine & Rehabilitation, 82(11),* 856-861.
20. Basmajian, J. V., Gowland, C. A., Brandstater, M. E., Swanson, L. R., & Trotter, J. (1982). EMG feedback treatment of upper limb in hemiplegic stroke patients: a pilot study. *Archives of Physical Medicine and Rehabilitation, 63(12),* 613-616.
21. Basmajian, J. V., Gowland, C. A., Finlayson, M. A., Hall, A. L., Swanson, L. R., Stratford, P. W. et al. (1987). Stroke treatment: comparison of integrated behavioral-physical therapy vs traditional physical therapy programs. *Archives of Physical Medicine and Rehabilitation, 68(5Pt1),* 267-272.
22. Bourbonnais, D., Bilodeau, S., Lepage, Y., Beaudoin, N., Gravel, D., & Forget, R. (2002). Effect of force-feedback treatments in patients with chronic motor deficits after a stroke. *American Journal of Physical Medicine & Rehabilitation, 81(12),* 890-897.
23. Bowman, B. R., Baker, L. L., & Waters, R. L. (1979). Positional feedback and electrical stimulation: an automated treatment for the hemiplegic wrist. *Archives of Physical Medicine and Rehabilitation, 60(11),* 497-502.
24. Croce, R., Horvat M., & Roswal, G. (1996). Augmented feedback for enhanced skill acquisition in individuals with traumatic brain injury. *Perceptual and Motor Skills, 82(2),* 507-514.
25. Crow, J. L., Lincoln, N. B., Nouri, F. M., & Weerdt, W. de (1989). The effectiveness of EMG biofeedback in the treatment of arm function after stroke. *International Disability Studies, 11(4),* 155-160.
26. Greenberg, S., & Fowler, R. S. Jr. (1980). Kinesthetic biofeedback: a treatment modality for elbow range of motion in hemiplegia. *American Journal of Occupational Therapy, 34(11),* 738-743.
27. Hurd, W. W., Pegram, V., & Nepomuceno, C. (1980). Comparison of actual and simulated EMG biofeedback in the treatment of hemiplegic patients. *American Journal of Physical Medicine, 59(2),* 73-82.
28. Inglis, J., Donald, M. W., Monga, T. N., Sproule, M., & Young, M. J. (1984). Electromyographic biofeedback and physical therapy of the hemiplegic upper limb. *Archives of Physical Medicine and Rehabilitation, 65(12),* 755-759.
29. Klose, K. J., Needham, B. M., Schmidt, D. L., Broton, J. G., & Green, B. A. (1993). An assessment of the contribution of electromyographic biofeedback as an adjunct therapy in the physical training of spinal cord injured persons. *Archives of Physical Medicine and Rehabilitation, 74(5),* 453-456.
30. Klose, K. J., Schmidt, D. L., Needham, B. M., Brucker, B. S., Green, B. A., & Ayyar, D. R. (1990). Rehabilitation therapy for patients with long-term spinal cord injuries. *Archives of Physical Medicine and Rehabilitation, 71(9),* 659-662.
31. Kohlmeyer, K. M., Hill, J. P., Yarkony, G. M., & Jaeger, R. J. (1996). Electrical stimulation and biofeedback effect on recovery of tenodesis grasp: a controlled study. *Archives of Physical Medicine and Rehabilitation, 77(7),* 702-706.
32. Lee, K. H., Hill, E., Johnston, R., & Smiehorowski, T. (1976). Myofeedback for muscle retraining in hemiplegic patients. *Archives of Physical Medicine and Rehabilitation, 57(12),* 588-591.
33. Lum, P. S., Burgar, C. G., Shor, P. C., Majmundar, M., & Loos, M. van der (2002). Robot-assisted movement training compared with conventional therapy techniques for the rehabilitation of upper-limb motor function after stroke. *Archives of Physical Medicine and Rehabilitation, 83(7),* 952-959.
34. Marchese, R., Diverio, M., Zucchi, F., Lentino, C., & Abbruzzese, G. (2000). The role of sensory cues in the rehabilitation of Parkinsonian patients: a comparison of two physical therapy protocols. *Movement Disorders, 15(5),* 879-883.

35. Mroczek, N., Halpern, D., & McHugh, R. (1978). Electromyographic feedback and physical therapy for neuromuscular retraining in hemiplegia. *Archives of Physical Medicine and Rehabilitation, 59(6),* 258-267.
36. Platz, T., Brown, R. G., & Marsden, C. D. (1998). Training improves the speed of aimed movements in Parkinson's disease. *Brain: a Journal of Neurology, 121(Pt 3),* 505-514.
37. Platz, T., Winter, T., Muller, N., Pinkowski, C., Eickhof, C., & Mauritz, K. H. (2001). Arm ability training for stroke and traumatic brain injury patients with mild arm paresis: a single-blind, randomized, controlled trial. *Archives of Physical Medicine and Rehabilitation, 82(7),* 961-968.
38. Shumaker, R. G. (1980). The response of manual motor functioning in Parkinsonians to frontal EMG biofeedback and progressive relaxation. *Biofeedback and Self-Regulation, 5(2),* 229-234.
39. Smith, K. N. (1979). Biofeedback in strokes. *The Australian Journal of Physiotherapy, 25,* 155-161.
40. Sunderland, A., Fletcher, D., Bradley, L., Tinson, D., Hewer, R. L., & Wade, D. T. (1994). Enhanced physical therapy improves recovery of arm function after stroke: a one year follow up study. *Journal of Neurology, Neurosurgery, and Psychiatry, 57(7),* 856-858.
41. Sunderland, A., Tinson, D. J., Bradley, E. L., Fletcher, D., Langton Hewer, R., & Wade, D. T. (1992). Enhanced physical therapy improves recovery of arm function after stroke. A randomised controlled trial. *Journal of Neurology, Neurosurgery, and Psychiatry, 55(7),* 530-535.
42. Talbot, M. L., & Junkala, J. (1981). The effects of auditorally augmented feedback on the eye-hand coordination of students with cerebral palsy. *American Journal of Occupational Therapy, 35(8),* 525-528.
43. Williams, J. M. (1982). Use of electromyographic biofeedback for pain reduction in the spastic hemiplegic shoulder: a pilot study. *Physiotherapy Canada, 34(6),* 327-333.
44. Wolf, S. L., Catlin, P. A., Blanton, S., Edelman, J., Lehrer, N., & Schroeder, D. (1994). Overcoming limitations in elbow movement in the presence of antagonist hyperactivity. *Physical Therapy, 74(9),* 826-835.
45. Wolf, S. L., LeCraw, D. E., & Barton, L. A. (1989). Comparison of motor copy and targeted biofeedback training techniques for restitution of upper extremity function among patients with neurologic disorders. *Physical Therapy, 69(9),* 715-735.
46. Lee, J. H. van der, Snels, I. A., Beckerman, H., & Lankhorst, G. J. (2001). Exercise therapy for arm function in stroke patients: a systematic review of randomized controlled trials. *Clinical Rehabilitation, 15(1),* 20-31.
47. Sutton, A. J., Abrams, K. R., Jones, D. R., Sheldon, T. A., & Song, F. (2000). *Methods for meta-analysis in medical research*. Chichester: John Wiley & Sons Ltd.

CHAPTER 3

Distance training for the restoration of motor function

H. van Dijk and H. J. Hermens

Journal of Telemedicine and Telecare 2004, 10(2), 63-71

Reprinted with permission

Abstract

We reviewed the literature on distance training for the restoration of motor function. Computerized literature searches were performed using the MEDLINE, EMBASE, Cinahl, and Cochrane databases. Articles that met the criteria for inclusion were divided into three general areas concerning the type of training in relation to motor functions – muscle / joint, balance, and cognition. From the publications identified in the literature search, 11 articles met the selection criteria. Six were related to the level of training of muscle / joint functions, four to balance functions, and one to cognitive functions. The articles were graded according to the strength of scientific evidence they offered. The review reveals some promising applications of distance motor training such as virtual reality (VR) and robotic devices. The strength of evidence from these studies was however poor, probably because the technology is relatively new. In contrast to the studies using VR and robotic devices, those using electromyographic (EMG) biofeedback showed a good to fair strength of scientific evidence. This can be explained by the substantial history of research on the restoration of motor function through the use of EMG biofeedback techniques. When implemented in clinical practice, these applications could reduce the pressure on scarce health care resources.

Introduction

Both the demographic changes in the population and the growing number of patients with chronic, work-related musculoskeletal disorders have major implications for health care resources[1]. Health care costs are rising and more professional care staffs are needed to maintain quality of care[2]. Health care resources have unfortunately not kept up with this growth. Therefore, waiting lists in clinics are growing and workload on caregivers is increasing. Consequently, waiting lists are lengthening and the workload of individual caregivers is increasing. Patients are being discharged earlier from hospital and rehabilitation centers to compensate this pressure[3,4]. Patients, who are discharged frequently, require support from professional and unpaid caregivers at home.

The increasing pressure on health care resources led us to design training programs that are extramural, i.e. they are delivered outside a hospital or rehabilitation center. For example, we have developed an extramural training program for the restoration of motor function. The concept of an inner and an outer feedback loop for the patient during his or her performance of a rehabilitation exercise was used in the development of the program. The inner feedback loop relates to the feedback provided by the application (e.g. virtual reality); this occurs without the presence of a health care professional. The outer feedback loop relates to the contact between the patient and the professional. Both loops concern augmented feedback, which is defined as information provided about the task that is supplemental to the sensory information typically received in the task[5].

Feedback through the inner loop focuses on the opportunity for patients to train themselves at a distance from the clinic (e.g. at home and work) without any expert present. To enable the patient to do so properly, augmented feedback regarding specific motor functions is provided. In this scenario, the outer feedback loop reflects the monitoring of patients by remote health care professionals – professionals can monitor improvements and supply information, when necessary, about the training.

We reviewed the literature on distance training for the restoration of motor function. Three categories of training could be distinguished:

1. **Muscle / joint**. Musculoskeletal disorders are often caused by work-related factors such as bad posture and repetitive movements. Work-related musculoskeletal disorders can be prevented, ameliorated, or cured by training patients to be aware of these causative factors[6]. In addition, musculoskeletal disorders are associated with many different illnesses, including stroke.

Intensive training of the affected side in hemiplegic stroke patients improves functional recovery of activities of daily living (ADL)[7-9].

2. **Balance**. Decreased equilibrium in standing and walking is a common problem associated with many different illnesses, including stroke[10]. Motor control training can improve balance in hemiplegic stroke patients.
3. **Cognition (psychomotor functions)**. Cognitive disabilities often result from brain injury (e.g. trauma and stroke). Common cognitive disabilities include memory loss and spatial disorientation[11]. Psychomotor training can decrease these disabilities[12].

Methods

Computerized literature searches to September 2003 were performed using MEDLINE, EMBASE, Cinahl, and Cochrane databases. Various keywords were used in a number of combinations with respect to the concept of distance training for the enhancement of motor functions (Table 1). The terms exercise therapy, rehabilitation, motor learning, motor activity, knowledge of results, knowledge of performance, telecommunication, telerehabilitation, telemedicine, Internet, home care, ambulatory care, remote, distance, and motor skills were combined in the literature search. In addition to this search, the references cited in relevant publications were checked.

Table 1. Search strategy

Step	Search term
1	training OR exercise therapy OR rehabilitation OR motor learning OR motor activity
2	feedback OR knowledge of results OR knowledge of performance
3	extramural care OR telecommunication OR telerehabilitation OR telemedicine OR Internet OR home care OR ambulatory care OR remote OR distance
4	motor function OR motor skills
5	1 AND 3
6	2 AND 3
7	1 AND 2 AND 3
8	1 AND 3 AND 4
9	1 AND 2 AND 3 AND 4
10	3 AND 4

The search outlined above was used for MEDLINE. Comparable strategies were used for EMBASE, Cinahl, and Cochrane. The words OR and AND were used to widen and focus the search.

Selection of publications

The following inclusion criteria were applied:

- The study had to involve motor functions training in at least one of the three categories – muscle / joint, balance, and cognition.
- The training had to be undertaken by the patient outside a hospital or rehabilitation center.
- The patient(s) had to receive augmented feedback (the inner and outer loop of feedback) as a feature of the training.
- The training had to be applied to at least one patient.
- The language had to be English, German, or Dutch.

The following were excluded:

- Review articles.
- Studies that focused on the training of non-patients.
- Articles that were duplicates of the same authors' other published studies – only the most representative of the studies was included for further consideration.

Initial screening of the articles was based on the content of the abstract. Two reviewers read all abstracts independently. Selection of relevant articles was based on the information obtained from the abstracts and was agreed upon in discussion.

Full-text articles were then evaluated independently by the authors, who then reached a consensus about whether or not the article should be included, using the selection criteria set out above. Articles that met the criteria for inclusion were classified in accordance with the three categories of motor functions training – muscle / joint, balance, and cognition.

In rating the strength of the evidence from each selected article, reference was made to the 9-level classification of Jovell and Navarro-Rubio[13] (Table 2). Any significant limitations of the studies, or the way in which they were reported, were noted.

Table 2. Classification of study design

Level	Strength of evidence	Type of study design
I	Good	Meta-analysis of Randomized Controlled Trials (RCTs)
II		Large-sample RCTs
III	Good to fair	Small-sample RCTs
IV		Non-randomized controlled prospective trials
V		Non-randomized controlled retrospective trials
VI	Fair	Cohort studies
VII		Case-control studies
VIII	Poor	Non-controlled clinical series; descriptive studies
IX		Anecdotes or case reports

Results

From the publications identified in the literature search, 96 were retrieved for closer inspection. Of these, 11 articles were judged to meet the selection criteria and were included in the review. The main reason for articles being excluded was that in these studies the motor functions training did not occur outside a hospital or rehabilitation center, i.e. did not occur at a distance.

Of the total of 11 remaining studies, six were related to training to restore muscle / joint function, four to the restoration of balance, and one to the enhancement of cognitive function. Table 3 summarizes the methods of these studies and Table 4 their findings.

Table 3. Summary of the methods used in studies of the restoration of motor function at a distance

Reference	Training objective	Procedure	Study design	Research population
Muscle / joint				
Burdea[14]	Finger strength, hand-eye coordination	2-mo VR training program	Level IX: case report (n=1)	No control
Jack[15]	Hand / fingers (affected side) ROM, speed of motion, fractionation, strength	VR-based exercise session consisted of 4 blocks of 10 trials. Multiple sessions were run for 10 d. Traditional exercises were also done. Patients were tested clinically before / after training	Level VIII: non-controlled clinical series (n=3)	Hemiplegic stroke patients (stroke occurred 3-6 yr before study); ages 50-83 yr; no control
Krebs[16]	Shoulder / elbow function (affected side)	E and C groups received conventional therapy. E group received additional 4-5 h a wk of robot-aided therapy; C group had 1 h a wk robot exposure. Procedure lasted for 7 wk and consisted of daily exercise with	Level IV: non-randomized controlled prospective trial (n=20: E, n=10; C,	Hemiplegic stroke patients; M age E group 58.5 yr (M wk post-stroke 2.8); M age C group 63 yr (M wk post-

Reference	Training objective	Procedure	Study design	Research population
		normal limb followed by 3 groups of 20 repetitions of daily exercise with impaired limb. Standard assessment procedure was used every other wk to assess patients	n=10)	stroke 3.2)
Reinkens-meyer[17]	Arm / hand function (affected side)	2-mo Web-based robotic therapy	Level VIII: non-controlled clinical series (n=4)	Hemiplegic stroke patients (stroke occurred 1-5 yr before study); ages 32-63 yr; no control
Hermens[6]	Muscle (upper trapezius) relaxation	Experiment started with baseline measurement (T0). Patients then received explanation about principles of myofeedback. 4-wk period (T1) of normal work with continuous myofeedback started. Patient was visited every wk to download stored data and discuss experiences. 4 wk later (T2), same measurements were performed	Level VIII: non-controlled clinical series (n=21)	Patients with computer work-related myalgia in neck / shoulder region; M age (SD) 30 (7 yr); no control
Petrofsky[18]	Reduction of Trendelenburg gait	2 h of conventional physical therapy each d for 2 mo. This involved 30 min of EMG biofeedback training. Half of group used, in addition, portable biofeedback device at home. Before / after therapy period, muscle tests, ROM, gait analysis were done	Level IV: non-randomized controlled prospective trial (n=10: E, n=5; C, n=5)	Patients with incomplete SCI suffering from paralysis; M age E group 26 yr (M deviations from normal hip excursion 31°); M age C group 24.8 yr (M deviations from normal hip excursion 32.6°)
Balance				
Cheng[20]	Standing postural symmetry, sit-to-stand	E and C groups received conventional therapy. In addition, E group used balance training device. Postural symmetry training required 30 min a d. After 15-min rest, patient performed sit-to-stand movement (20 min). Training protocol was performed 5 d a wk for 3 wk. All patients were tested at beginning of training, again at 6-mo follow-up	Level III: small-sample RCT (n=54: E, n=30; C, n=24)	Hemiplegic stroke patients; M age (SD) E group 62.3 (8.0) yr (M wk post-stroke 2.8 (1.4)); M age C group 63.1 (7.8) yr (M wk post-stroke 2.9 (1.2))
A. M. Wong[21]	Standing postural control	E group was trained with weight-bearing biofeedback training device; C group with traditional standing training table. Each subject was trained	Level III: small-sample RCT (n=60: E, n=30; C,	Stroke / TBI patients with unilateral hemiplegia or hemiparesis; M

Reference	Training objective	Procedure	Study design	Research population
		for 20 min a session, 5 sessions per wk for 3-4 wk. Both groups received identical tests before / after each training session	n=30)	age (SD) E group 52.5 yr (14.8); M age C group 52.8 yr (12.4)
Engardt[22]	Symmetrical body-weight distribution	Patients carried out conventional physiotherapy during course of study. Added was training program of rising / sitting down with vertical ground reaction force feedback in E group; without in C group. Training comprised 15-min sessions, 3 times a d, 5 d a wk for 6 wk. Patients were tested before / after training period	Level III: small-sample RCT (n=40: E, n=20; C, n=20)	Hemiplegic stroke patients; M age (SD) E group 64.6 (6.7) yr (M d post-stroke 38 (18)); M age C group 65.1 (9.0) yr (M d post-stroke 38 (22))
M. S. Wong[23]	Postural control	Postural training device had to be worn for 18 mo. Scoliosis clinic was arranged for pre-application visit, first mo of application, then every 3 mo. Data were downloaded on every clinic d. Clinical assessments were performed pre-application, at every follow-up clinic	Level VIII: non-controlled clinical series (n=16)	Adolescent idiopathic scoliosis patients (Cobb's angle 25-35°). M age (SD) 12.1 (1.2) yr; no control
Cognition				
Gourlay[11]	Daily living skills	Virtual kitchen	Level IX: anecdote or case report	Cognitively impaired patients; no control

Muscle / joint

Study design and quality

The applications to restore muscle / joint function at a distance involved virtual reality (VR)[14,15], robotic devices[16,17], and electromyographic (EMG) biofeedback[6,18]. In terms of study design, four studies were considered to provide weak evidence, corresponding to the categories VIII and IX from Jovell and Navarro-Rubio's list[13]. The remaining two studies were categorized as providing good to fair evidence (level IV).

The degree of scientific rigor of the four studies that were considered poor varied considerably. Two studies[14,17] provided virtually no information on procedures for selection of patients or on the measurement protocol. The outcome measures used were not well defined or clinically not very relevant. The exceptions were the non-controlled clinical trials performed by Hermens and Hutten[6] and Jack et al.[15]. These studies showed few limitations the way they were performed and reported. The studies by Krebs et al.[16] and Petrofsky[18], which were considered to provide good to fair evidence based on their design, gave an extensive description of patient selection procedures and measurement protocols; also, their outcome measures were clinically relevant and results were presented clearly.

Virtual reality

The Rutgers glove[14,15] is a component of a project at Rutgers University that is examining telerehabilitation with virtual force feedback. This telerehabilitation system is being tested in pre-clinical trials. Future studies will be required to establish measurement reliability, the predictive validity of training and its ability to improve patient function. Exercise units for the elbow, knee, and ankle are being designed.

Robotic devices

Initial clinical trials with the MIT-MANUS[16] device (Massachusetts Institute of Technology – MANUS) indicated that it can improve arm movement ability in stroke patients. Home use of these devices is probably not feasible in the immediate future because of the high costs and large size of the equipment.

The Web-based telerehabilitation system developed by Reinkensmeyer et al.[17] could offer a good alternative[19]. Their study showed that, like robotic therapy devices, commercially available force-feedback joysticks can be used to stimulate the sense of touch and movement, and can apply therapeutic patterns of forces to the hand and arm as the user attempts to move. Unlike larger robotic devices, force-feedback joysticks could become movement trainers because they can be purchased cheaply. Future research will be needed to identify which combination of activities performed at what intensity best promotes movement recovery.

EMG biofeedback

The portable myofeedback system of Hermens and Hutten[6] was designed to be used outside the laboratory, for example in the home or workplace. In this way, the training obtained is quite intensive, much more than would be obtained in a therapeutic environment, and without the burden of decreasing labor productivity. An additional reason for choosing an ambulatory system is the finding in training studies that learned behavior is often coupled to the learned environment[5], and it is far from obvious that behavior learned in a certain set of tasks is readily transferred to other tasks. These same reasons led Petrofsky[18] to use a portable EMG biofeedback device for home use.

The results of the studies of Hermens and Hutten[6] and Petrofsky[18] clearly indicated that the use of ambulatory myofeedback can result in a change of the muscle function. A large international randomized clinical trial is now being set up.

Table 4. Applications used and results in studies of the restoration of motor function at a distance

Reference	Application	Feedback Inner loop	Feedback Outer loop	Training effect
Muscle / joint				
Burdea[14]	VR-based orthopedic telerehabilitation system. System consisted of pair of similar PCs at patient's home and clinic, connected via Internet. Home station consisted of Rutgers Master II force-feedback glove, multi-purpose control interface, Web camera, microphone array. Clinic PC was used to store / analyze exercise data	Force (Rutgers Master II), visual (monitor) feedback	Telecommunication between home, clinic through telephone, camera, Internet	Increase in finger grasping force and improvement of hand-eye coordination
Jack[15]	VR-based orthopedic telerehabilitation system (see Burdea above). Home system used 2 input devices: CyberGlove (used in exercises that involved position measurement), Rutgers Master II force-feedback glove (used in force-exertion exercises)	Force (Rutgers Master II), visual (monitor), auditory (therapist), performance (digital performance meter) feedback	Telecommunication between home / clinic through telephone, camera, Internet	Objective measurements showed: thumb ROM, improvement of 16-69%; thumb angular speed, improvement of 3-80%; finger fractionation, improvement of 11%, 43%; a decrease of 22%; thumb mechanical work, improvement of 9-25%; hand grasping force (dynamometer measurement), improvement of 13-59%. Subjective evaluation by patients was positive
Krebs[16]	MIT-MANUS (2 degrees of	Visual (monitor), auditory	Telecommunication between patient /	E group improved further / faster, outranking C

Reference	Application	Feedback Inner loop	Feedback Outer loop	Training effect
	freedom). Computer-controlled system modulated way robot reacted to mechanical perturbation from patient. MIT-MANUS could move, guide, perturb movement of patient's upper limb and could record motions, mechanical quantities such as position, velocity, forces applied. Present design was portable. Robot control was implemented on PC. PC displayed exercise. Workstation included second PC for clinician	(speakers) feedback	clinician through online video / audio information (telephone). In classroom / group sessions, clinician worked with more than 1 patient at a time. In self-care therapy at home, clinician telementored outpatient via bilateral link between robot at home and robot in clinic	group in clinical assessments of motor impairment involving shoulder / elbow
Reinkens-meyer[17]	Telerehabilitation system consisted of Web-based library of status tests (speed, coordination, strength, finger speed test), therapy games progress charts. It could be used with variety of input devices, including low-cost force-feedback joystick capable of assisting / resisting movement	Force (e.g. joystick), visual (monitor), performance (progress charts) feedback	Users / caregivers could assess rehabilitation progress via Web	For severe and moderate cases, therapy seemed to be beneficial as performance improved initially. Severe cases began to worsen towards end of experiment. Interest in participating curtailed after about 6 wk of therapy
Hermens[6]	Portable myofeedback system designed to be used outside	Tactile feedback. Vibration was provided during short period of time, which could	Data logger	Directly after myofeedback decrease in pain / discomfort was shown. For neck region, showing decrease in

Reference	Application	Feedback Inner loop	Feedback Outer loop	Training effect
	laboratory, continuously. Harness of bandages was developed that could be altered to fit individual, to enable quick / reproducible placement of bipolar surface EMG electrodes on upper trapezius muscles. Embedded software provided muscle rest detection / parameterization	be increased, when alarm was not met after number of consecutive occasions		visual analogue score from 3.5 to 2.2 at T1, further decrease to 1.5 at T2, only difference between scores at T0 and T2 was significant. For shoulder region, showing decrease from 3.3 to 2.4 at T1, further decrease to 1.6 at T2, both scores were significantly different. Left / right trapezius muscles showed increase in relative rest time from T0 to T1, further increase at T2. Only significant change in relative rest time was found during typing task on left side
Petrofsky[18]	Portable EMG biofeedback device. Microprocessor was used to analyze data in real-time. 2-channel EMG amplifier and analyzer were employed. Surface electrodes placed bilaterally and 0.02 m apart were used to record EMG signals from 2 gluteus medius muscles. 2 switches were placed across front and back of foot. Output of switches was sampled as input to parallel port on microprocessor	Auditory feedback. When pattern of muscle activity was too low, audio trigger alerted patient; when gait was too slow, series of 3 beeps at end of each step alerted patient to walk faster on affected side	Therapist could set controls on device for more gluteus medius activity in each cycle or for faster or slower step	Patients only undergoing clinical therapy showed about 50% reduction in hip drop due to therapy. E group that used home training device showed almost normal gait after 2 mo
Balance				
Cheng[20]	Biofeedback standing balance training device that consisted of 2 foot pressure sensing platforms for	Visual feedback. Real-time visual weight-bearing display with 2 numerical light displays / light balance scale	Auditory system was included to give online instruction and alarm signal	In E group body weight was distributed significantly more symmetrically, with less mediolateral sway in centre of pressure when rising / sitting down. C

Reference	Application	Feedback Inner loop	Feedback Outer loop	Training effect
	weight-bearing, postural correction mirror for upper extremity postural training, real-time visual weight-bearing information, hand suspension / hip fixation system, worktable, hand exercise boards	were mounted on centre portion of postural correction mirror. Mirror was engraved with series of rectangular grid lines used for visual feedback		group showed no significant difference between beginning of training and follow-up. At follow-up, 10 of the 24 patients (41.7%) in C group had fallen, compared with only 5 of 30 patients (16.7%) in E group
A. M. Wong[21]	Biofeedback standing balance training device (see Cheng, above)	As above	As above	There was effect of biofeedback on stance symmetry. After 4 wk of training, postural asymmetry in group E / C was reduced from M (SD) of 17.2% (10.8%) and 17.0% (10.0%) to 3.5% (2.2%) and 10.1% (6.4%), respectively
Engardt[22]	Vertical ground reaction force-feedback device. Force-feedback platform consisted of 2 electronic balances, which could sense vertical forces separately from each foot. To allow easy use at home, it was small / light and could be run with a battery. 2 balances were connected to electronic circuit, which registered the difference of load on them	Auditory feedback. When load on paretic leg was above a threshold ratio corresponding to 20%, 30%, 40%, 50% of total body weight, auditory signal was delivered. Level was selected according to patient's weight distribution and was increased stepwise until patient could load 50% of total body weight on paretic leg	Data logger	M (SD) difference in improvement of body-weight distribution on paretic leg of 13.2% (10.7%) of total body weight in E group and 5.1% (6.7%) in the C group in rising and 12.7 (7.5%) total body weight and 4.6% (6.6%) in sitting down tests. Improvements in physical performance and sit-to-stand tests were greater in E group than in C group
M.S. Wong[23]	Audio-biofeedback postural training device, which consisted of 5 main components: casing, integrated circuit board, torso and	Auditory feedback. When incorrect posture had been assumed for more than 20 s, barely audible tone was produced. This tone became	Data logger and therapist could adjust level of difficulty	In first 18 mo, 3 patients defaulted and 4 showed curve progression > 10°. Curves for other 9 patients were kept under control (within 5° of Cobb's angle); there were no significant differences between pre-application value and values at 6

Reference	Application	Feedback Inner loop	Feedback Outer loop	Training effect
	respiration encoder, torso spool, respiration spool. There were 10 levels of difficulty. Device was placed on chest / back of patient with a harness. It contained data logger to detect wearing time	louder if poor posture was maintained for additional 20 s. Tone terminated when satisfactory posture was adopted		successive trials
Cognition				
Gourlay[11]	Networked virtual rehabilitation system (home and clinic PC). VR glove was developed to enable patient to pick up and move objects. VR glove sensory input device (only in home unit) consisted of glove, bend sensors, motion-translation unit. Variable resistive bend sensors were attached to each finger of ordinary glove. Database stored all movements	Visual (monitor) feedback. Addition of tactile feedback to each fingertip was considered	Telecommunication between patient and clinician through chat box, teleconferencing, telephone	Increasing evidence that pointed to a transfer of daily living skills from VR to real world, for patients with cognitive / motor problems

Abbreviations:
E group, experimental group; C group, control group; RCT, randomized controlled trial; ROM, range of motion; VR, virtual reality; EMG, electromyographic; SCI, spinal cord injury; TBI, traumatic brain injury; ROM, range of motion; M, mean; SD, standard deviation; yr, year(s); mo, month(s); wk, week(s); d, day(s); h, hour(s); min, minute(s); s, second(s)

Balance

Study design and quality

The applications to restore balance at a distance all involved biofeedback[20-23]. In terms of study design, three of the four studies were considered to provide good to fair evidence. The remaining study was considered to offer poor-quality evidence.

The degree of scientific rigor of the three randomized controlled trials was similar. In all three studies, the selection of patients and the measurement protocol was well described. The sample size of the experimental group (n=30) differed from that of the control group (n=24) in the study by Cheng et al.[20]. The reason for this remains unclear. The category VIII study of Wong M. S. et al.[23] in fact had few limitations. The patient selection procedure and the measurement protocol were well reported.

Biofeedback

Cheng et al.[20] and Wong A. M. et al.[21] found that visual and auditory clues used as an external aids for stroke patients improved their stability, leading to less asymmetry in weight bearing and consequently decreasing the number of falls. Wong A. M. et al.[21] studied only the immediate effects after a 4-week training period, whereas Cheng et al.[20] added a 6-month follow-up measurement in their study. The biofeedback standing balance device could be constructed easily. It used simple, low-cost hardware, which made it suitable for use in both hospital and the patient’s home.

Like the postural symmetry biofeedback training device described above, Engardt et al.[22] constructed a training device that was easy to use at home (being small, light weight, and battery driven). The device was supplied with only auditory feedback. This was enough to demonstrate an improvement in body-weight distribution, physical performance, and sit-to-stand ability.

Wong M. S. et al.[23] evaluated the effectiveness of an audio-biofeedback postural training device for adolescent patients with idiopathic scoliosis. Before such a postural training device can become a treatment modality, a long-term study with more patients will be necessary.

Cognition

Study design and quality

The single application to restore aspects of cognition at a distance involved VR. In terms of design, the study of Gourlay et al.[11] was considered to offer poor-quality evidence. No patient data were provided.

Virtual reality

Gourlay et al.[11] created a prototype system that combined VR and telemedicine, and that enabled the rehabilitation of one or more patients. A mistake by the patient could be played back by the therapist and the recording paused at the critical point. All movements and interactions could be recorded in a database and analyzed when required. This enabled the patient and therapist to analyze past performance. Although promising, this prototype would require further research to establish measurement reliability, the predictive validity of training and its ability to improve patient function.

Discussion

The present review was performed to gain insight into the possibilities for the provision of rehabilitation therapy at a distance. We compiled an inventory of the applications that fitted into the concept of distance training for the restoration of motor functions. Four different types of applications had been reported: virtual reality, robotic devices, EMG biofeedback, and other types of biofeedback. Six articles were related to the restoration of muscle / joint functions, four articles related to the restoration of balance, and only one article to the enhancement of cognitive function.

A few applications fitted extremely well into the concept of training at a distance, for example the VR applications developed by the Rutgers University[14,15] and by the National University of Singapore[11] and the Web-based telerehabilitation system developed by Reinkensmeyer et al.[17] However, it should be noted that the strength of evidence regarding these studies was poor. This is perhaps because the telecommunications technology has only recently become affordable for the practice of medicine[24]. Also, VR and robotic devices have only recently been incorporated into the training of patients at home or work. Therefore, it is not surprising that well designed evaluation studies are still lacking.

In contrast to the majority of studies that employed VR or robotic devices, most of those using biofeedback[20-23] or EMG biofeedback[6,18] showed a good to fair strength of scientific evidence. This can be explained by the fact that there has been substantial research into the use of biofeedback, in particular EMG biofeedback, in the restoration of motor function[25,26]. The research has primarily been carried out in a rehabilitation setting, without the availability of an outer feedback loop. The development and implementation of this outer feedback loop within EMG biofeedback application is improving slowly. In the studies on EMG biofeedback, the outer feedback loop has involved rather primitive types of communication between the patients and the expert in comparison to the telecommunication used in the other types of application discussed above. The use of a data logger and the setting of device controls by a therapist can be considered as remote monitoring of the patient by an expert. Although primitive, this type of communication nonetheless makes it possible for the professionals to monitor the improvements, to supply information and to adjust the training.

The present review suggests that there are a few applications that could be used for the restoration of motor training at a distance. When implemented in clinical practice, they could reduce the pressure on health care resources, although the expense, at least at present, of VR applications and robotic devices would limit their ability to do so. In this respect, the Web-based telerehabilitation system developed by Reinkensmeyer et al.[17] appears promising because affordable costs and access via Internet have the potential to make the system widely accessible.

References

1. Seshamani, M., & Gray, A. (2002). The impact of ageing on expenditures in the National Health Service. Age *and Ageing, 31(4),* 287-294.
2. Buckley, B. M. (2001). Healthy ageing: ageing safely. *European Heart Journal, 3 Supplement N,* 6-10.
3. Caplan, G., Board, N., Paten, A., Tazelaar-Molinia, J., Crowe, P., Yap, S. J. et al. (1999). Decreasing lengths of stay: the cost of the community. *Australian and New Zealand Journal of Surgery, 69(6),* 433-437.
4. Bendz, M., Castledine, G., Soderback, I., Carvalho, G., & Sapountzi-Krepia, D. (2002). Discharge of frail older people from acute hospitals across Europe. *British Journal of Nursing, 11(2),* 111-115.
5. Schmidt, R. A., & Lee, T. D. (1999). *Motor control and learning: a behavioural emphasis*. 3rd ed. Champaign: Human Kinetics.
6. Hermens, H. J., & Hutten, M. M. R. (2002). Muscle activation in chronic pain: its treatment using a new approach of myofeedback. *International Journal of Industrial Ergonomics, 30(3-4),* 325-336.
7. Butefisch, C., Hummelsheim, H., Denzler, P., & Mauritz, K. H. (1995). Repetitive training of isolated movements improves the outcome of motor rehabilitation of the centrally paretic hand. *Journal of Neurological Sciences, 130(1),* 59-68.
8. Kwakkel, G., Wagenaar, R. C., Twisk, J. W., Lankhorst, G. J., & Koetsier, J. C. (1999). Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial. *Lancet, 354(9174),* 191-196.
9. Taub, E., & Morris, D. M. (2001). Constraint-induced movement therapy to enhance recovery after stroke. *Current Atherosclerosis Reports, 3(4),* 279-286.
10. Chen, I. C., Cheng, P. T., Hu, A. L., Liaw, M. Y., Chen, L. R., Hong, W. H. et al. (2000). Balance evaluation in hemiplegic stroke patients. *Chang Gung Medical Journal, 23(6),* 339-347.
11. Gourlay, D., Lun, K. C., Lee, Y. N., & Tay, J. (2000). Virtual reality for relearning daily living skills. *International Journal of Medical Informatics, 60(3),* 255-261.
12. Hooft, I. van 't, Andersson, K., Sejersen, T., Bartfai, A., & Wendt, L. von (2003). Attention and memory training in children with acquired brain injuries. *Acta Paediatrica, 92(8),* 935-940.
13. Jovell, A. J., & Navarro-Rubio, M. D. (1995). Evaluation of scientific evidence. *Medicina Clinica, 105(19),* 740-743.
14. Burdea, G., Popescu, V., Hentz, V., & Colbert, K. (2000). Virtual reality-based orthopedic telerehabilitation. *IEEE Transactions on Rehabilitation Engineering, 8(3),* 430-432.
15. Jack, D., Boian, R., Merians, A. S., Tremaine, M., Burdea, G. C., Adamovich, S. V. et al. (2001). Virtual reality-enhanced stroke rehabilitation. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 9(3),* 308-318.
16. Krebs, H. I., Hogan, N., Aisen, M. L., & Volpe, B. T. (1998). Robot-aided neurorehabilitation. *IEEE Transactions on Rehabilitation Engineering, 6(1),* 75-87.
17. Reinkensmeyer, D. J., Pang, C. T., Nessler, J. A., & Painter, C. C. (2002). Web-based telerehabilitation for the upper extremity after stroke. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 10(2),* 102-108.
18. Petrofsky, J. S. (2001). The use of electromyogram biofeedback to reduce Trendelenburg gait. *European Journal of Applied Physiology, 85(5),* 491-495.
19. Java therapy. Retrieved October 24, 2003, from http://www.javatherapy.com.

20. Cheng, P. T., Wu, S. H., Liaw, M. Y., Wong, M. K., & Tang, F. T. (2001). Symmetrical body-weight distribution training in stroke patients and its effect on fall prevention. *Archives of Physical Medicine and Rehabilitation, 82(12),* 1650-1654.
21. Wong, A. M., Lee, M. Y., Kuo, J. K., & Tang, F. T. (1997). The development and clinical evaluation of a standing biofeedback trainer. *Journal of Rehabilitation Research and Development, 34(3),* 322-327.
22. Engardt, M., Ribbe, T., & Olsson, E. (1993). Vertical ground reaction force feedback to enhance stroke patients' symmetrical body-weight distribution while rising / sitting down. *Scandinavian Journal of Rehabilitation Medicine, 25(1),* 41-48.
23. Wong, M. S., Mak, A. F., Luk, K. D., Evans, J. H., & Brown, B. (2001). Effectiveness of audio-biofeedback in postural training for adolescent idiopathic scoliosis patients. *Prosthetics and Orthotics International; 25(1),* 60-70.
24. Bergeron, B. P. (2003). Virtual reality applications in clinical medicine. *Journal of Medical Practice Management, 18(4),* 211-215.
25. Basmaijan, J. V. (1989). *Biofeedback: principles and practice for clinicians*. 3rd ed. Baltimore: Williams & Wilkins.
26. Schwartz, M. S. (1995). *Biofeedback: a practitioner's guide*. 2nd ed. New York: The Guilford Press.

CHAPTER 4

Providing additional information to compensate for age-related declines in task performance

H. van Dijk, A. J. R. Stoter, T. Mulder, and H. J. Hermens

Submitted

Abstract

Two experiments were performed to explore if providing additional information can compensate for the age-related declines in task performance. In experiment 1, adding information such as external cues and/or augmented feedback enhanced performance in young and older adults. The decline in performance found in the elderly subjects was not fully compensated; i.e. older adults receiving cues and feedback did not perform the task on a similar level as young adults did without this information. In experiment 2, it was examined whether age-related decline in performance can be further compensated by optimizing the way in which the additional information is presented. The impact of two modality conditions (visual; visual & auditory) was studied. The results indicate no differences between both conditions.

Introduction

Throughout their lives, people learn many motor skills, from riding a bicycle as a child to walking with a cane as an elderly person. The learning of motor skills is a process in which motor processes continuously interact with cognitive and sensory processes[1,2]. These processes tend to change when people grow older. Information processing becomes slower (see Salthouse[3]; Welford[4] for a review), which limits the response flexibility of the system[5]. In addition, several studies have reported sensory deficits with advanced age[6,7]. Loss of sensory sensitivity as a result of deterioration of structure and function implies that older adults are impaired in the fast and selective use of information from sensory modalities[8].

The changes in cognitive processing associated with aging cause a decline in performance on experimental tasks[9]. Indeed, performance can be seen as a result of the subtle balance between the task conditions (exogenous factors) and the subjects' capabilities to handle these conditions (endogenous factors). It is thought that a shift in this balance occurs as people age, i.e. the influence of endogenous factors shows a relative decline, whereas the dependence on exogenous factors increases[10,11]. This implicates that older adults depend, more than young adults, on the available external information (exogenous factors) to compensate for their decline in performance. External information may facilitate task performance by providing additional information such as external cues or augmented feedback to the subject. Several studies with young adults demonstrated a positive effect of external cues (e.g. Janelle et al.[12]) and augmented feedback (e.g. Mulder & Hulstijn[13]) on the performance of sensorimotor tasks. Swinnen et al.[14] extended this research to older adults. They concluded that performance (of a bimanual coordination task) during the normal vision condition was less successful than during the augmented feedback condition. This was the case for both young and older adults.

Information can be presented in a variety of ways. In optimizing the way in which additional information is presented to the elderly subject, the importance of carefully selecting the appropriate sensory modality must be emphasized[8]. A proposed method to increase the effective capacity of information processing in older adults is to present information in a dual rather than single mode of presentation (e.g. presenting a diagram visually with corresponding text in an audio form rather than employing only the visual mode)[15]. This 'modality effect' emerges from the assumption that information processing consists of (at least) two mode-specific components (visual and auditory), each of which has a limited capacity[16]. Using visual text and pictures alone may exceed the capacities of the visual component since both the screen text and graphics would be competing for the (limited) resources of the visual component. Using a dual mode instead of a single mode may enhance information processing capacity as the information is now distributed across several components[17].

The goal of the present study was to explore if providing additional information can compensate for age-related declines in task performance. Two related experiments were performed focusing on two aspects of providing information to young and older adults. In the first experiment, the influence of adding information was studied; external cues and augmented feedback were used as sources of additional information. The effects of external cues and augmented feedback were examined by comparing the impact of these conditions (external cues alone; external cues and augmented feedback together) to a normal vision condition (no additional information available). We expected that adding information to the task would improve the performance of both young and older adults.

In the second experiment, the influence of the way in which the additional information is provided to the subject was studied in both age groups. The effects of two conditions using the same information (external cues and augmented feedback together) were compared: a single mode of presentation (visual modality) and a dual mode (visual and auditory modality). We expected that the latter condition would result in a better performance for both age categories.

EXPERIMENT 1

Methods

Subjects

Thirty-two healthy subjects within two age categories (16 young adults: mean age 26.7 years, standard deviation (SD) 3.6; and 16 older adults: mean age 57.5 years, SD 7.5) participated in this experiment. The age categories were balanced for gender (6 male and 10 female). Subjects were excluded from the study if they suffered from deafness, (color-)blindness, or hand-related impairments (e.g. rheumatoid arthritis). Recruitment of the young adults was performed under the employee-population (also graduate students) of Roessingh Research and Development, the University of Twente, and the University of Groningen in the Netherlands. Older adults were recruited among the wider circle of acquaintances of the researchers. The study was approved by the Roessingh ethics committee. All subjects signed an informed consent before they participated in the experiment.

Procedure

All subjects performed three blocks in random order. Each block was preceded by a period of practice assisted by the researcher, so that subjects were accustomed to the conditions of the block. One block consisted of five different trials. Between blocks, subjects took a 10-min rest.

1. **Normal vision condition**. No additional information was available.
2. **Cue condition**. Task-related information was added in the form of external cues (hand positions were connected to a color cue).
3. **Cue & feedback condition**. Task-related information was added in the form of external cues and augmented feedback (hand positions were connected to a color cue and feedback was provided when an error was made).

Task

The task used in the present study required subjects to repeat a growing sequence of simple hand positions. The task consists of two modes: firstly, the computer mode in which the computer presented a growing sequence of positions in steps; secondly, the real-time mode in which the subjects repeated the presented steps of the hand-position sequence. The real-time hand and the computer hand look more or less identical.

A response-trial consisted of a total sequence of 16 hand positions. The sequence grows in steps of two (see Table 1). After presenting the first two hand positions in the computer mode, the subjects responds by repeating these positions in the real-time mode. The first two positions are then repeated and added by another two positions in the computer mode; followed again by repetition of the now four hand positions in the real-time mode. Subjects were instructed to respond as accurately as possible. As the sequence grows, response complexity increases. The optimal length of the steps and sequences was determined by pilot-testing preceding the present study. The sequences were constructed to be ambiguous such that there was no possibility to predict the order of the hand positions. Direct repetition of the same position was avoided, i.e. the same position could not appear directly after itself.

Table 1. Example of repetition sequence of hand movements

Presentation in computer mode		Correct response in real-time mode	
Hand position	2 & 4 2 & 4 & 3 & 4 2 & 4 & 3 & 4 & 1 & 2 Etc.	Hand position	2 & 4 2 & 4 & 3 & 4 2 & 4 & 3 & 4 & 1 & 2

There were four different hand positions (see Figure 1). These hand positions could be presented with specific **external cues** such as color, i.e. the color of the background of the screen changed according to a specific hand position: position 1 was coded red, position 2 green, position 3 white, and position 4 blue. This accounts for the computer and real-time mode. In addition, **augmented feedback** could be provided when an error was made in the sequence of actions, i.e. the color linked to the erroneous position blinked. Logically, this accounts only for the real-time mode.

1. Horizontal with fingers stretched – back of the hand up.
2. Horizontal with fingers closed – back of the hand up.
3. Vertical with fingers stretched – thumb up.
4. Vertical with fingers closed – thumb up.

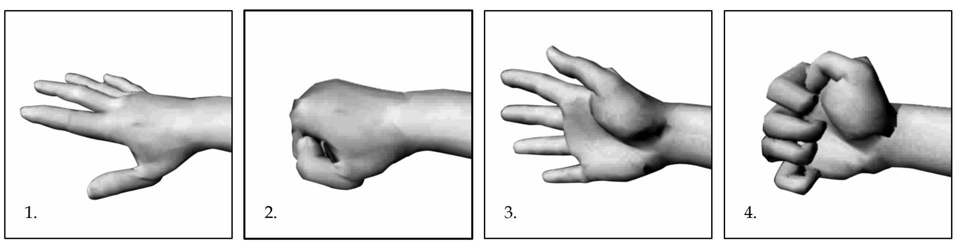

Figure 1. Four hand position

Apparatus

The hand positions were digitized using the CyberGlove (Immersion, Co., San Jose, CA). The CyberGlove is an instrumented data glove that provides high-accuracy joint-angle measurements. It uses proprietary resistive bend-sensing technology to accurately transform hand and finger motions into real-time digital joint-angle data. Software converts the data into a real-time graphical hand that mirrors the movements of the physical hand. The real-sized hand was shown on a computer screen from the same angle as the subjects saw their own hand. Subjects were seated behind a table facing the computer screen while wearing the CyberGlove on their dominant hand. The screen was positioned at approximately 50 cm in front of the subjects.

A motion tracker (Xsens Technologies BV, Enschede, the Netherlands) was attached to the data glove (on top of the wrist) to provide for the rotation of the hand. The motion tracker is a miniature inertial measurement unit providing serial digital output of 3D acceleration, 3D rate of turn, and 3D earth-magnetic field data. It provides accurate 3D orientation data in real-time.

Data analysis

The correctness of response was used as outcome measure. Mean scores of the five trials were calculated for each block. The outcome measure was analyzed using a two (age categories) x three (conditions) x eight (sequence trial) analyses of variance (ANOVA) with repeated measures on the last factor. The Greenhouse-Geisser correction factor for degrees of freedom was used in all ANOVAs. Post-hoc contrasts on significant main effects were performed using the Bonferroni procedure. Alpha was set at .05 for all statistical tests.

Results

Correctness of response

Performance of young and older adults under the conditions normal, cue and cue & feedback is illustrated in Figure 2.

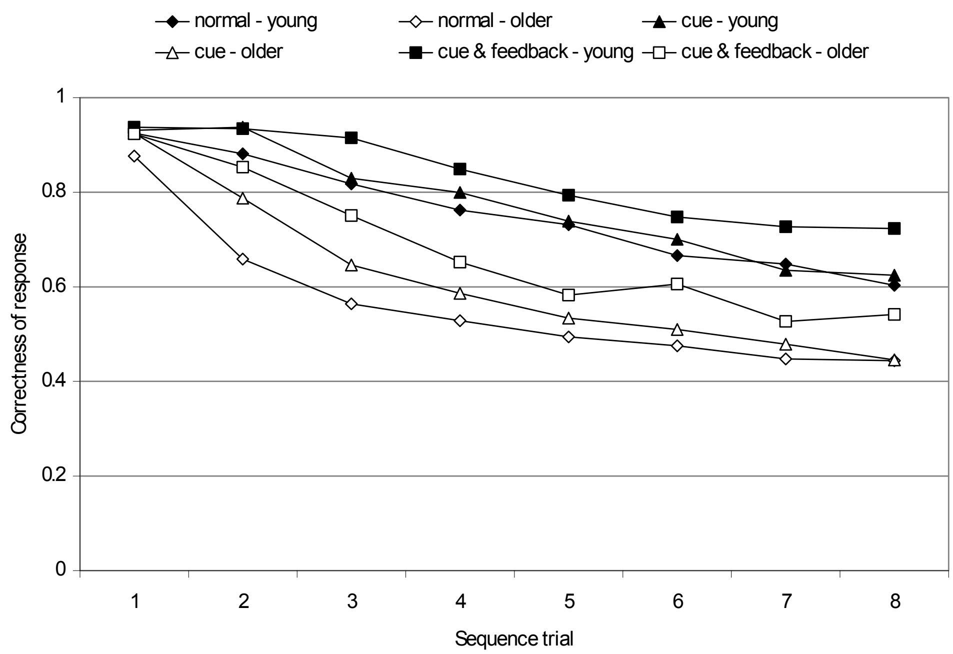

Figure 2. Correctness of response comparing young and older adults as a function of sequence trial under the conditions normal, cue, and cue & feedback

As was indicated by a significant main effect for sequence trial (F = 176.15, p = .000), the performance level of all subjects decreased as task complexity increased. Young and older adults showed a difference in accuracy as they performed the task, i.e. a significant main effect for age category was found (F = 55.23, p = .000). Young adults showed a higher level of performance compared to older adults. The interaction between age category and sequence trial was also significant (F = 10.51, p = .000).

There was a significant main effect for condition (F = 6.25, p = .003). Post-hoc analysis revealed significant differences between the normal and cue & feedback condition (95% CI from -0.16 to -0.03, p = .002). Herewith, there was no difference between young and older adults, as was shown by the absence of a significant interaction effect between age category and condition (F = 0.35, p = .70).

EXPERIMENT 2

Methods

Subjects

Thirty-three healthy subjects within two age categories (16 young adults: mean age 26.6 years, SD 3.5; and 16 older adults: mean age 57.2 years, SD 7.6) participated in this experiment. The age categories were balanced for gender (5 male and 11 female). Subjects were excluded from the study if they suffered from deafness, (color-)blindness, or suffered from hand-related impairments. Recruitment of the subjects was comparable to experiment 1. The study was approved by the Roessingh ethics committee. All subjects signed an informed consent before they participated in the experiment.

Apparatus, task, procedure, and data analysis

The procedure, the sequential hand-position task, the apparatus, and data analysis were the same as those described in experiment 1, with a few exceptions outlined below. In experiment 2, all subjects performed two blocks in random order. Between the blocks, subjects took a 10-min rest. Block 1 was similar to block 3 in experiment 1.

1. **Color condition**. Hand position were connected to the external cue color, i.e. position 1 was coded red, position 2 green, position 3 white, and position 4 blue, and augmented feedback was provided when an error was made, i.e. the color connected to the erroneous position blinked.
2. **Color & tone condition**. Hand position were connected to the external cue color & tone, i.e. position 1 was coded red with a very low beep, position 2 was coded green with a low beep, position 3 was coded white with a high beep, and position 4 was coded blue with a very high beep, and augmented feedback was provided when an error was made, i.e. the color connected to the specific position blinked and an error tone was heard.

Results

Correctness of response

The performance of young and older adults in the conditions normal, color, and color and tone is illustrated in Figure 3.

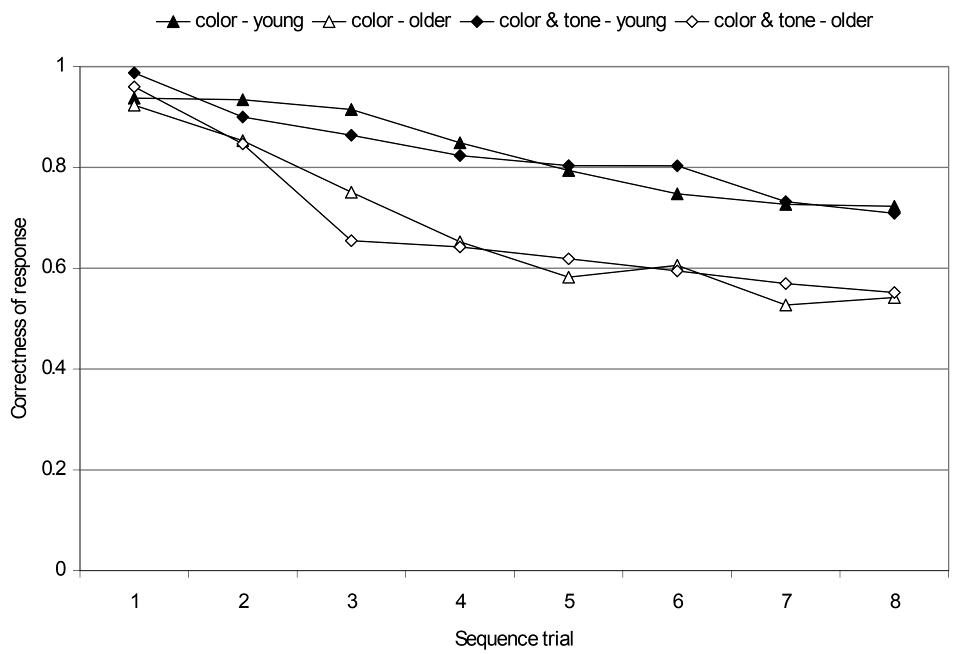

Figure 3. Correctness of response comparing young and older adults as a function of sequence trial under the conditions color and color & tone

All subjects decreased their level of performance as task complexity increased. This was indicated by a significant main effect for sequence trial (F = 112.71, p = .000). There was a significant main effect for age category (F = 31.25, p = .000). This means that there was a difference in level of performance between the young and older adults. The interaction between age category and sequence trial was also significant (F = 9.21, p = .000). The correctness of response was higher for young adults compared to older adults.

Subjects using the color modality did not perform differently from subjects using the color & tone modality. This was indicated by a non-significant main effect for condition (F = 0.06, p = .81). Herewith, there was no difference between young and older adults, as was shown by the absence of a significant interaction effect between age category and condition ($F = 0.05$, $p = .83$).

Discussion

In the present study, two related experiments were performed to explore if providing additional information can compensate for the age-related declines in task performance. Experiment 1 focused on the influence of adding information to the sequential position task. In accordance to the results of earlier studies (e.g. Janelle et al.[12]; Mulder & Hulstijn[13]; Swinnen et al.[14]), the present study indicates that adding information such as external cues and/or augmented feedback indeed enhances the level of performance in both young and older adults. The cues and feedback offered the subjects a strategy to learn the sequence of hand positions. Specific hand positions could be coded to specific color cues. This coding allowed the development of a reference-of-correctness against which the sequence was successively modified by appropriate feedback, and was used for covert rehearsal techniques[18]. Augmented feedback provided the subjects with a basis for changing the attempts on the subsequent trial, thus guiding the learner to the correct strategy[13].

The observed levels of performance were found to be significantly lower in older than in young adults. This was expected given the changes in cognitive processing associated with aging[3,4,5]. Could this age-related decline in performance be compensated by adding external cues and/or augmented feedback to the task at hand? Providing external cues and augmented feedback together indeed significantly enhanced the level of performance in older adults. However, the decline in performance was not fully compensated, i.e. older adults receiving cues and feedback together did not perform the sequential position task on a similar level as the young adults did without using this additional information.

Following experiment 1, it was examined whether the age-related declines in performance could be further compensated by optimizing the way in which the additional information is presented to the elderly subject. Using external cues and augmented feedback together, the impact of two modality conditions (visual and visual & auditory) was studied in experiment 2. Guidelines for multimedia instruction derived from the cognitive load theory suggest that the effective capacity of information processing increases when information is presented in a dual rather than a single mode[15,17]. Especially in the elderly subjects, where the capacity for fast information processing is reduced[5], this could be an effective method to compensate for their declines in performance. When the cognitive load of the task is high, as in the present task when the sequence grows long, an advantage was expected by using a dual mode instead of a single mode. This advantage was however not apparent in the present study, i.e. the results indicated no difference between both modality conditions for young and older adults. This suggests that presenting additional information in a dual mode is not a successful method for compensating for the age-related performance decline on the position sequence task. A possible explanation for the lack of differences between both modality conditions lies in the visual dominance of the present sequential task. It is commonly found that when the input from vision and other modalities is put in conflict, visual dominance results[15]. Behavior in this situation suggests that subjects respond to the visual information and disregard that provided by the auditory information.

The results of experiment 2 indicate that there was no interaction effect between age category and modality condition, meaning that the effects of the different modalities are similar in both young and older adults. This is in accordance with the results of earlier studies examining age-related learning effects on different types of augmented feedback[19-22].

To summarize, we found that older adults demonstrated greater difficulty with acquiring the complex sequential task than their young counterparts, i.e. older adults showed a lower level of performance than young adults in both experiments. This is in agreement with evidence from previous work[9]. This finding is important since many everyday tasks involve such complex action sequences. The age-related declines in sequence performance make it more difficult for older people to (re-)acquire new skills or to adjust to subtle changes in their environment. Adding information such as external cues and augmented feedback to the task at hand proofs to be a promising method to compensate for the age-related declines in performance. On the other hand, presenting the information in a dual (visual & auditory) instead of a single (visual) mode does not further improve task performance in the elderly people.

References

1. Hochstenbach, J., & Mulder, T. (1999). Neuropsychology and the relearning of motor skills following stroke. *International Journal of Rehabilitation Research, 22(1),* 11-19.
2. Mulder, T., & Hochstenbach, J. B. (2003). Motor control and learning: implications for neurological rehabilitation. In R. J. Greenwood (Ed.), *Handbook of neurological rehabilitation* (pp. 143-157). New York: Psychology Press.
3. Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403-428.
4. Welford, A. T. (1984). Between bodily changes and performance: some possible reasons for slowing with age. *Experimental Aging Research, 10(2),* 73-88.
5. Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adults age differences in working memory. *Developmental Psychology, 27,* 763-776.
6. Fozard, J. L., & Gordon-Salant, S. (2001). Changes in vision and hearing with aging. In J. E. Birren, & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 241-266). 5th ed. New York: Academic Press.
7. Seidler, R. D., & Stelmach, G. E. (1995). Reduction in sensorimotor control with age. *Quest, 47,* 386-394.
8. Serrien, D. J., Teasdale, N., Bard, C., & Fleury, M. (1996). Age-related differences in the integration of sensory information during the execution of a bimanual coordination task. *Journal of Motor Behavior, 28(4),* 337-347.
9. Salthouse, T. A. (1990). Working memory as a processing resource in cognitive aging. *Developmental Review, 10,* 101-124.
10. Cornelius, S. W., & Caspi, A. (1986). Self-perceptions of intellectual control and aging. *Educational Gerontology, 12(4),* 345-357.
11. Lachman, M. E. (1991). Perceived control over memory aging: developmental and intervention perspectives. *Journal of Social Issues, 47,* 159-175.
12. Janelle, C. M., Champenoy, J. D., Coombes, S. A., & Mousseau, M. B. (2003). Mechanisms of attentional cueing during observational learning to facilitate motor skill acquisition. *Journal of Sports Sciences, 21(10),* 825-238.
13. Mulder, T., & Hulstijn, W. (1985). Sensory feedback in the learning of a novel motor task. *Journal of Motor Behavior, 17(1),* 110-128.
14. Swinnen, S. P., Verschueren, S. M., Bogaerts, H., Dounskaia, N., Lee, T. D., Stelmach, G. E. et al. (1998). Age-related deficits in motor learning and differences in feedback processing during the production of a bimanual coordination pattern. *Cognitive Neuropsychology, 15,* 439-466.
15. Wickens, C. D., & Hollands, J. G. (1999). *Engineering psychology and human performance*. 3rd ed. Upper Saddle River: Prentice-Hall Inc.
16. Baddeley, A. (1992). Working memory. *Science, 255,* 556-559.
17. Tindall-Ford, S., Chandler, P., & Sweller, J. (1997). When two sensory modes are better then one. *Journal of Experimental Psychology: Applied, 3(3),* 257-287.
18. Newell, K. M. (1991). Motor skill acquisition. *Annual Review of Psychology, 42,* 213-237.
19. Carnahan, H., Vandervoort, A. A., & Swanson, L. R. (1996). The influence of summary knowledge of results and aging on motor learning. *Research Quarterly for Exercise and Sport, 67(3),* 280-287.
20. Swanson, L. R., & Lee, T. D. (1992). Effects of aging and schedules of knowledge of results on motor learning. *Journal of Gerontology: Psychological Sciences, 47(6),* 406-411.

21. Wiegand, R. L., & Ramella, R. (1983). The effect of practice and temporal location of knowledge of results on the motor performance of older adults. *Journal of Gerontology, 38(6),* 701-706.
22. Wishart, L. R., & Lee, T. D. (1997). Effects of aging and reduced relative frequency of knowledge of results on learning a motor skill. *Perceptual and Motor Skills, 84(3Pt1),* 1107-1122.

CHAPTER 5

Effects of age and content of augmented feedback on learning an isometric force-production task

H. van Dijk, T. Mulder, and H. J. Hermens

Submitted

Abstract

This study addressed the interaction between age and the informational content of feedback on the acquisition and retention of an isometric force-production task. Healthy subjects (30 young adults: 20 to 35 years; 30 older adults: 55 to 70 years) were randomly assigned to a certain feedback condition: knowledge of results or kinetic feedback. The results show no differences between young and older adults in the accuracy and consistency of motor performance (regardless of feedback condition). There were no interactions of age with any of the feedback-related variables. These findings suggest that the effects of augmented feedback on motor skill learning are similar in both young and older adults.

Introduction

The majority of research on aging and motor behavior to date has focused on processes that affect the control of movement. An excellent overview of these findings is provided by Spirduso[1]. Research on aging and the learning of motor skills has not received much attention. With aging however, the ability to learn new skills remains crucial for maximizing function and quality of life – as a part of new job training, recreational pursuits, and rehabilitation therapy.

The motor learning process is thought to consist of different stages, with the early stage requiring active cognitive processing[2-4]. Research findings suggest that there are changes in cognitive processing associated with aging[5]. Information processing becomes slower, which limits the response flexibility of the system[6]. In addition, changes in the way older adults perform movements are found[1]. Given the decline in cognitive processes that accompany aging, combined with the age-related changes in motor control, there is reason to suspect that learning variables such as type of augmented feedback operate differently in older adults than they do in young adults. The limited evidence available suggests that despite the changes associated with aging, older adults benefit from augmented feedback similarly to young adults[7-10]. The learning variables concerned in these studies were summary augmented feedback[7], schedules of augmented feedback[8], temporal location of augmented feedback[9], and frequency of augmented feedback[10].

The present study is focused on the effects of age and learning variables on motor skill learning. The learning variable addressed is the informational content of augmented feedback. Augmented feedback provides information to the performer relative to the outcome of the previous response. This information is processed and a decision is made regarding the nature of the modifications required to the action plan on succeeding trials so that the level of performance may be improved. Thus, the informational content of the feedback is viewed as an important determinant of the success of the ensuing action. In motor learning research, two types of augmented feedback are roughly distinguished in which the content of information differs: knowledge of results (KR) and knowledge of performance (KP)[3,4]. Knowledge of results refers to information about the outcome of the movement in relation to the task goal. Knowledge of performance consists of information about the movement pattern that led to the performance outcome. Even though logical and theoretical distinctions between these two broad classes of augmented feedback have been made, an operational distinction between them is sometimes lacking. For example, the movement pattern used to perform a task can be isomorphic with the task goal such as in dance or figure skating. In these cases, the task requires the performance of one specific movement pattern that is equal to the task goal. As a result, feedback about the movement pattern (KP) is essentially equivalent to feedback about the goal achievement (KR).

Nevertheless, feedback about the movement pattern contains more information than knowledge of results, which only provides outcome information of the movement. In the present study, we used the term kinetic feedback for information about the movement-pattern kinetics, referring to aspects of force and timing. We prefer this term to knowledge of performance since it is less confusing as to what information the feedback contains.

The research comparing the two types of augmented feedback suggests that kinetic feedback is of more benefit in learning motor skills than knowledge of results (see Newell et al.[11]; Newell & Walter[12]; Swinnen[13] for a review). However, this is likely to be dependent on the complexity of the learned task. Newell et al.[14] concluded in their research that the basis for determining the most appropriate augmented feedback for motor skill learning is specified by an analysis of the task goal in that the feedback must match the imposed task constraints. Thus, if the task goal is the production of a simple discrete force value, then knowledge of results of that force parameter is sufficient to optimize performance. On the other hand, if the task goal is the production of a more complex, specific force-time curve, then presentation of the response force-time history is more potent than knowledge of results of any discrete force parameter. In the present study, we used a complex force-production task.

Research on the type of information that feedback should contain to facilitate the acquisition of a task has not been a focus of investigation as a function of age. Of particular interest is whether the impact of the two types of feedback, knowledge of results and kinetic feedback on motor skill learning is similar for young and older adults, especially considering the age-related differences in cognitive processing and motor control. Thus, the purpose of the present study was to examine the combined effect of age and content of augmented feedback on the acquisition and retention of a complex force-production task. Based on previous findings suggesting that older adults benefit from learning variables similarly to young adults[7-10], we expected that the informational content of feedback has similar learning effects on both young and older adults.

Methods

Subjects

Healthy, able-bodied subjects within two age categories (young adults: 20 to 35 years; and older adults: 55 to 70 years) participated in this experiment. To be included in the study, subjects had to be free of any history of upper extremity pathology. Young adults were recruited under the employee-population (also graduate students) of Roessingh Research and Development and the University of Twente in Enschede, the Netherlands. Older adults were recruited among the wider circle of acquaintances of the researchers. The study was approved by the Roessingh ethics committee. All subjects signed an informed consent before they participated in the experiment.

In total, 60 subjects (30 young adults and 30 older adults) were recruited for the study. The subjects of both age categories were randomly assigned to two experimental groups with the restriction that the groups were balanced for gender. Fifteen subjects were assigned to each group (5 males and 10 females per group). The young subjects had a mean age of 25.5 years (SD = 3.7) and the older subjects a mean age of 58.7 years (SD = 5.3). Subjects had no prior experience with the experimental task and were not aware of the specific purposes of the study.

Apparatus

The apparatus was a static force measurement system consisting of a force transducer (Thermonobel, Karlskoga, Sweden) and an amplifier that converted the physical force into a voltage representing the instantaneous value of the applied force. The voltage was recorded by using a 16-bits analogue-to-digital converter installed in a microcomputer programmed to sample at 1 kHz. Targets and applied forces were displayed on a computer screen. The load cell was attached to an adjustable metal frame.

Task and procedure

The subjects were positioned upright on a stool, and the load cell was adjusted so that the subject’s wrist contacted the load cell comfortably while the elbow was positioned at 90 degrees of flexion. The shoulder joint was in a neutral, resting position so any elbow extension force was generated in line with the load cell. The computer screen was positioned approximately 50 cm directly in front of the subjects.

The motor task used in this study required subjects to use their dominant elbow extensors to generate an isometric force in such a way as to replicate a predetermined bi-amplitude force of 5 s as closely as possible (shown in Figure 1). The bi-amplitude task required that subjects were able to control force amplitude at two different levels and to control the relaxation of the elbow extensors as well. This task seems one that most adults cannot perform well upon initial assessment, but which can be learned if practiced and if the subject is provided with augmented feedback. Comparable isometric force-production tasks were also used in studies performed by Brisson and Alain[15] and Vander Linden et al.[16].

In an isometric force task, the length of the muscle-tendon complex remains essentially unchanged; therefore, limb position also remains unchanged. This task was used because it allows fewer environmental and biomechanical factors to influence performance than does a task that requires actual movement.

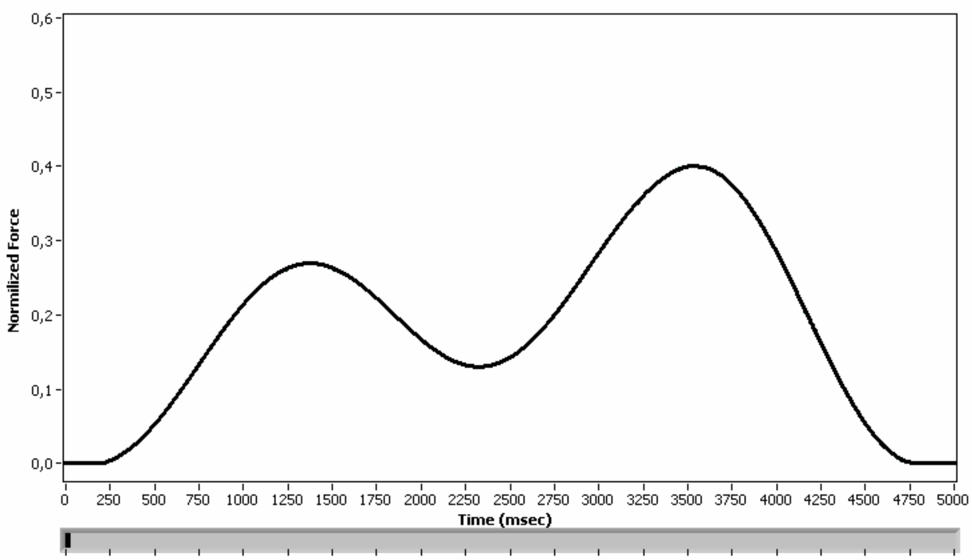

Figure 1. The criterion waveform of the bi-amplitude force of 5 s

The criterion waveform was displayed on the computer screen and was supported by a timekeeper (a bar below the waveform) that showed the progression in time of the 5-s task. The maximum force required for the task was 40% of the maximum voluntary contraction (MVC) of the subjects around which young and older adults measured their optimal consistency in isometric tasks according to the study of Smits-Engelsman et al[17]. The MVC was estimated prior to the first trial by three measurements of each 3 s with 45 s rest in between. The subjects were instructed to press as hard as possible on the load cell using their elbow extensors. The highest produced force was used to calculate the required waveform force. If the third measurement showed the highest force, another measurement was performed (with a maximum of 5 measurements). The young subjects showed a mean MVC of 156.6 N (SD = 33.8) and the older subjects a mean MVC of 144.8 N (SD = 29.2).

The subjects were then instructed to exert force against the load cell in an attempt to produce a pattern of force that resembled as closely as possible the waveform displayed on the computer screen. The criterion waveform was not shown to the subjects during the instructional period; subjects were allowed to see it for the first time during the first trial. The criterion waveform was shown to the subjects throughout baseline, acquisition, and retention measurements.

The 60 selected subjects were randomly assigned to two experimental feedback groups. The groups differed in content of information that was fed back to the subjects related to the extent of force and timing errors:

1. **Knowledge of results (KR)**. Knowledge of results was provided by means of displaying on the screen the average absolute error (root mean square error) for the 5-s trial.
2. **Kinetic feedback (kinFB)**. Kinetic feedback was provided by means of overlaying the produced force onto the criterion waveform.

The investigator initiated each trial by counting down from three to zero. The count down was used to make it easier for the subjects to time when to initiate the movement. Approximately 2 s after completion of the response, the error score was shown on the screen or the produced force was overlaid onto the criterion waveform, i.e. augmented feedback was presented after the trial (terminal augmented feedback). Subjects were then allowed to view the presented feedback with the criterion waveform for 6 s. After this, the screen was cleared, and a next trial was started.

Baseline measurements consisted of one block of 20 trials without any augmented feedback regarding the produced force. In the acquisition measurements, the subjects practiced (with augmented feedback provided) for five blocks of each 20 trials. Upon completing the acquisition measurements, subjects rested for 10 min after which an immediate retention test (short-term) was administered. To study delayed retention, a retention test (long-term) was administered after 7 days had elapsed. Both retention tests involved one block of 20 trials without any augmented feedback provided (similar to baseline measurements). During all tests, a 1-min resting period was provided after each block of 20 trials.

The used training procedure had a comparable amount of practice (and subsequent augmented feedback exposure) to the studies of Brisson and Alain[15] and Vander Linden et al.[16].

Data analysis

An overall accuracy measurement known as root mean square error (RMSE) was calculated by determining the absolute difference between the task force and the criterion waveform force at each data point (2-ms interval) and averaging across all data points for each 5-s trial. The mean of these scores was calculated for each block of 20 trials and represented a measure of accuracy (called constant error or CE). The standard deviation of the different scores within each block of 20 trials (within subjects) was computed and represented a measure of consistency (called variable error or VE).

To check the randomization procedure for both young and older adults, the dependent measures CE and VE were analyzed in a two sample *t* test for baseline measurements comparing the two feedback conditions separately for the age categories. Additional analyses were conducted to determine the temporary performance effects (in acquisition) and relatively permanent changes that occur with learning (in retention). The acquisition data were analyzed using a two (age categories) x two (types of feedback) x six (baseline and acquisition blocks) analyses of variance (ANOVA) with repeated measures on the last factor for both dependent measures (CE and VE). The retention data were analyzed with a similar design, except that there were only two blocks (short- and long-term retention). The Greenhouse-Geisser correction factor for degrees of freedom was used in all ANOVAs. Alpha was set at .05 for all statistical tests.

Results

Baseline block

No significant differences were found between the two types of feedback, knowledge of results and kinetic feedback on both dependent measures for young adults (CE: 95% confidence interval (CI) from -7.68 to 7.28, $p = .96$; VE: 95% CI from -2.81 to 2.88, $p = .98$) and for older adults (CE: 95% CI from -14.24 to 13.54, $p = .96$; VE: 95% CI from -2.22 to 3.32, $p = .69$). Therefore, randomization was considered satisfactory for both age categories.

A remarkable finding in the baseline measurements was the statistical significant difference found for CE between both age categories regardless of the type of feedback provided (95% CI from -16.06 to -0.88, p = .03). No significant difference was found for VE (95% CI from -1.88 to 1.92, p = .98).

Acquisition blocks

The dependent measures CE and VE are plotted as a function of blocks for both age category and type of feedback in Figure 2 and Figure 3, respectively.

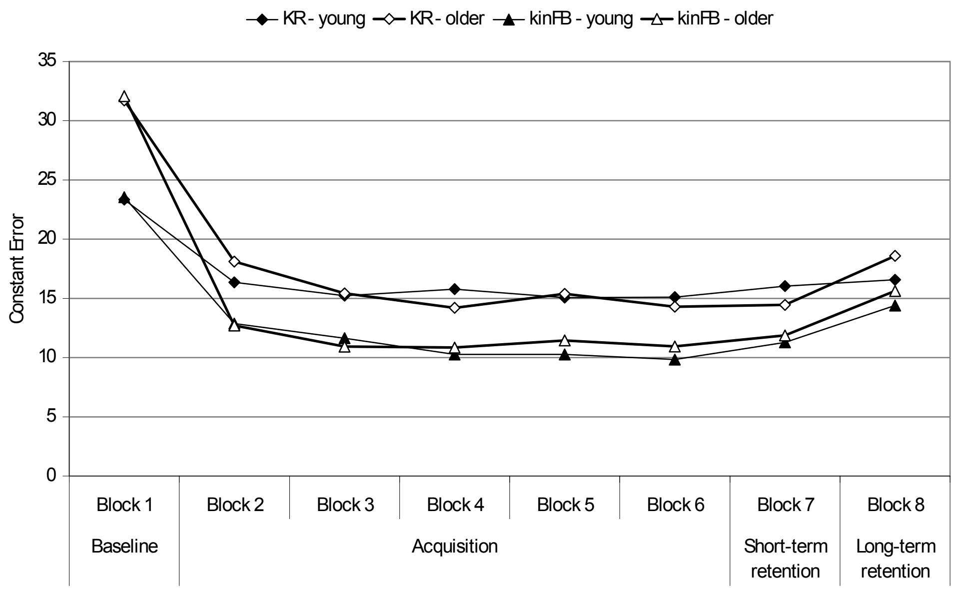

Figure 2. Constant Error as a function of types of feedback and blocks for baseline, acquisition, and retention

All subjects improved their performance on the force-production task during acquisition as was indicated by a statistical significant main effect for block (CE: F = 52.97, p = .000). No significant main effect was found for age category (CE: F = 1.75, p = .19). This means that there was no difference between the young and older adults as they performed the task. The interaction between age category and block was however statistically significant (CE: F = 4.65, p = .03). As was illustrated by Figure 2, this was caused by the different baseline levels of accuracy (see also results of Baseline Block).

Subjects using kinetic feedback performed the force-production task better than subjects using knowledge of results. This was illustrated by Figure 2 and indicated by a statistical significant main effect for type of feedback (CE: F = 10.57, p = .002).

The absence of a significant interaction effect between age category and type of feedback (CE: F = 0.09, p = .77) indicated no difference between young and older adults with this.

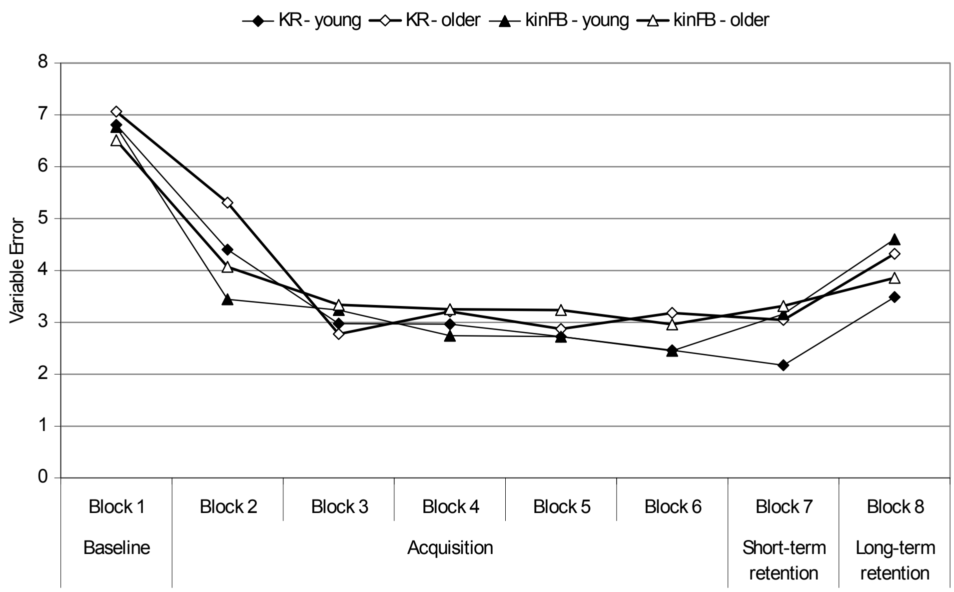

Figure 3. Variable Error as a function of types of feedback and blocks for baseline, acquisition, and retention

All subjects had less variability in their performance over blocks as was indicated by a significant main effect for block (VE: F = 36.71, p = .000). No significant main effects were found for type of feedback (VE: F = 0.12, p = .73) and for age category (VE: F = 0.75, p = .39). Also, the interaction effect (age category x type of feedback) was not statistically significant (VE: F = 0.00, p = .97).

Retention blocks

The results of the retention analysis indicated that all subjects deteriorated their performance as was indicated by a statistical significant main effect for block (CE: F = 16.59, p = .000). Herewith, there was no difference between young and older adults as was shown by the non-significant main effect for age category (CE: F = 0.03, p = .87) and by the non-significant interaction effect (age category x block) (CE: F = 3.11, p = .09).

A statistical significant main effect for type of feedback was found (CE: $F = 5.89$, $p = .02$). Supported by Figure 2, this means a better learning effect for the force-production task using kinetic feedback compared to knowledge of results. There was no difference between both age categories with this as was indicated by the non-significant interaction effect (age category x type of feedback) (CE: $F = 0.00$, $p = .97$).

Subjects showed more variability in their performance during retention as was indicated by a significant main effect for block (VE: $F = 10.20$, $p = .003$). No significant main effects were found for type of feedback (VE: $F = 0.48$, $p = .49$) and for age category (VE: $F = 0.25$, $p = .62$). Also, the interaction effect (age category x type of feedback) was not statistically significant (VE: $F = 2.16$, $p = .15$).

Discussion

The present study addressed the interaction between age and the content of augmented feedback on the acquisition and retention of an isometric force-production task. The results indicate that there were no differences in the accuracy and consistency of motor performance and learning between young and older adults. There were no interactions of age with any of the feedback-related learning variables. These findings support previous research indicating that the effects of augmented feedback are similar in both young and older adults[7-10].

Newell et al.[14] concluded in their research that the most appropriate augmented feedback for motor skill learning must match the imposed task constraints. The detected difference in the accuracy between both types of augmented feedback suggests that kinetic feedback indeed matches the imposed complexity of the learned task in the present study more than knowledge of results. This accounts for both young and older adults. In comparing the results to other studies using knowledge of results, it is important to emphasize that the knowledge of results used in the present study contained 'non-redundant' information with that available from intrinsic feedback (e.g. vision, audition, and proprioception). This is not always the case as shown in the study of Zubiaur et al.[18]. In learning the overhead serve in volleyball, they provided feedback on the outcome of the action. The knowledge of results used brings no new information to the subjects, who are able to observe the outcome themselves.

Despite the changes associated with aging, the accuracy and consistency of performance and learning (regardless of the type of augmented feedback) was similar for both young and older adults. This contradicts the results of other studies examining aging effects (e.g. Durkin et al.[19]; Smits-Engelsman et al.[17]). In the study by Durkin et al.[19], older adults (with a mean age of 55.9 years that is comparable to the present study) demonstrated a decline in performance in both a pursuit rotor and a mirror reading task. The motor control study of Smits-Engelsman et al.[17] showed an age-related deterioration in the consistency of performance in isometric force regulation (age 5 to 93 years). Carnahan et al.[5] however revealed a similar lack of age-related differences in their study – similar to the present study – using a group of older adults with a mean age of 75.0 years (range 67 to 79). One of their explanations was that the task used (a computer-key pressing task in a specified goal time) may not have been complex enough to identify age-related differences. Motor control research suggests that as task complexity increases, the difference between young and older adults also increases[1]. An example thereof is provided by Light and Spirduso[20]. Utilizing a 2-choice reaction time paradigm, movement complexity as a factor of response programming was varied. The speed of response programming was found to be age dependent and to interact with movement complexity across age groups. Although, the task used in the present study is considered a complex force-production task (compared to other force-production tasks used in motor learning research such as the mono-amplitude force curve used by Newell et al.[14]) this explanation might also be valid in our study.

A potentially alternative explanation for the lack of age-related differences can be derived from the inhibition deficit hypothesis, referred to by Swinnen et al.[21]. They argued that learning new motor skills in older adults is more susceptible to the influence of previous learning compared to younger adults. Old habits, over-learned tasks, and natural preferred or automated processes seem particularly difficult for older adults to inhibit when trying to perform tasks in which these processes must be suppressed. The task used in the present study is probably not subject to this because it concerned a ‘new’ motor skill without the influence of previous learning. Hence, the task could be learned equally well by both young and older adults.

The only difference between both age categories was the constant error at baseline level of performance (not the variable error). During the baseline measurements (without any augmented feedback provided) older adults overestimated the force required for the task more than young adults does. This might be caused by the general deterioration of sensory functions as a result of aging[22]. Indeed, the absence of augmented feedback would force the subjects to pay more attention to the visual and proprioceptive feedback (intrinsic) sources to guide the performance.

To summarize, we found no evidence that aging influences the way by which augmented feedback facilitates motor learning in this specific force-production task. This accounts for both knowledge of results and kinetic feedback. However, this does not exclude the possibility that the process underlying the learning effects differs between young and older adults. Older adults may need more effort to accomplish a similar result as their young counterparts. The present study supports the general finding that the most appropriate augmented feedback for motor skill learning must match the imposed task constraints. As task complexity increases, it becomes increasingly difficult to succinctly and meaningfully describe the actions in terms of feedback to the performer. There are limitations in the subject's ability to use information about movement kinetics, especially as people age. Future research should address this problem.

References

1. Spirduso, W. W. (2005). *Physical dimensions of aging*. 2nd ed. Champaign: Human Kinetics.
2. Fitts, P. M., & Posner, M. I. (1967). *Human performance*. Belmont: Brooks/Cole.
3. Magill, R. A. (2001). *Motor learning: concepts and applications*. 6th ed. New York: McGraw-Hill.
4. Schmidt, R. A., & Lee, T. D. (1999). *Motor control and learning: a behavioural emphasis*. 3rd ed. Champaign: Human Kinetics.
5. Salthouse, T. A. (1990). Working memory as a processing resource in cognitive aging. *Developmental Review, 10,* 101-124.
6. Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403-428.
7. Carnahan, H., Vandervoort, A. A., & Swanson, L. R. (1996). The influence of summary knowledge of results and aging on motor learning. *Research Quarterly for Exercise and Sport, 67(3),* 280-287.
8. Swanson, L. R., & Lee, T. D. (1992). Effects of aging and schedules of knowledge of results on motor learning. *Journal of Gerontology: Psychological Sciences, 47(6),* 406-411.
9. Wiegand, R. L., & Ramella, R. (1983). The effect of practice and temporal location of knowledge of results on the motor performance of older adults. *Journal of Gerontology, 38(6),* 701-706.
10. Wishart, L. R., & Lee, T. D. (1997). Effects of aging and reduced relative frequency of knowledge of results on learning a motor skill. *Perceptual and Motor Skills, 84(3Pt1),* 1107-1122.
11. Newell, K. M., Morris, L. R., & Scully, D. M. (1985). Augmented information and the acquisition of skill in physical activity. In R. L. Terjung (Ed.), *Exercise and sport sciences reviews* (Vol. 13, pp. 235-261). New York: Macmillan.
12. Newell, K. M., & Walter, C. B. (1981). Kinematic and kinetic parameters as information feedback in motor skill acquisition. *Journal of Human Movement Studies, 7,* 235-254.
13. Swinnen, S. P. (1996). Information feedback for motor skill learning: a review. In H. N. Zelaznik (Ed.), *Advances in motor learning and control* (pp. 37-66). Champaign: Human Kinetics.
14. Newell, K. M., Sparrow, W. A., & Quinn, J. T. (1985). Kinetic information feedback for learning isometric tasks. *Journal of Human Movement Studies, 11,* 113-123.
15. Brisson, T. A., & Alain, C. (1997). A comparison of two references for using knowledge of performance in a motor task. *Journal of Motor Behavior, 29(4),* 339-350.
16. Vander Linden, D. W., Cauraugh, J. H., & Greene, T. A. (1993). The effect of frequency of kinetic feedback on learning an isometric force production task in nondisabled subjects. *Physical Therapy, 73(2),* 79-87.
17. Smits-Engelsman, B. C. M., Galen, G. P. van, & Duysens, J. E. J. (2004). Force levels in uni- and bimanual isometric tasks affect variability measures differently throughout lifespan. *Motor Control, 8 (4),* 437-450.
18. Zubiaur, M., Ona, A., & Delgado, J. (1999). Learning volleyball serves: a preliminary study of the effects of knowledge of performance and of results. *Perceptual and Motor Skills, 89(1),* 223-232.
19. Durkin, M., Prescott, L., Furchtgott, E., Cantor, J., & Powell, D. A. (1995). Performance but not acquisition of skill learning is severely impaired in the elderly. *Archives of Gerontology and Geriatrics, 20,* 167-183.
20. Light, K. E., & Spirduso, W. W. (1990). Effects of adult aging on the movement complexity factor of response programming. *Journal of Gerontology, 45(3),* 107-109.
21. Swinnen, S. P., Verschueren, S. M., Bogaerts, H., Dounskaia, N., Lee, T. D., Stelmach, G. E. et al. (1998). Age-related deficits in motor learning and differences in feedback processing

during the production of a bimanual coordination pattern. *Cognitive Neuropsychology, 15(5),* 439-466.

22. Seidler, R. D., & Stelmach, G. E. (1995). Reduction in sensorimotor control with age. *Quest, 47*, 386-394.

CHAPTER 6

Effects of age and timing of augmented feedback on learning muscle relaxation while performing a gross motor task

H. van Dijk and H. J. Hermens

American Journal of Physical Medicine & Rehabilitation (accepted)

Abstract

Objective: To examine the combined effect of age and timing of augmented feedback on learning muscle relaxation. Performing a gross motor task, subjects had to lower their trapezius muscle activity using the electromyographic signal as visual myofeedback.

Design: Healthy subjects (16 young adults: 20 to 35 years; and 16 older adults: 55 to 70 years) were randomly assigned to one of two timing conditions of myofeedback: concurrent (feedback was provided immediately during the trial) and terminal (feedback was provided delayed after the trial) condition.

Results: The results indicate that young adults had a higher level of motor performance (lower muscle activity) compared to older adults (regardless of feedback condition). In contrast to young adults, older adults did not improve their performance throughout the experiment. There were no interactions of age with the timing conditions of myofeedback during acquisition and retention.

Conclusions: Either timing condition of augmented feedback was equally helpful to young adults, while neither was helpful for older adults in learning muscle relaxation.

Introduction

Learning new motor skills is essential across the lifespan for our everyday adaptation to the environment. With aging, the ability to learn new skills continues to be crucial for maximizing function and quality of life. For example, older adults may need to learn new skills such as a leisure activity or an adaptation task such as propelling a wheelchair. Although there is an abundance of research on how young adults learn motor skills, little is known about whether older adults learn skills in the same way as young adults.

One general conclusion from motor learning research using young adults is that the learning of motor skills is a problem-solving process that requires cognitive intervention between perception and action, particularly in the early stages of skill acquisition[1,2]. Aging may influence how older adults use information in this early, highly cognitive stage. Research findings suggest that there are changes in cognitive processing associated with aging[3]. In addition to these cognitive changes, there is evidence that there are changes in how older adults perform movements[4]. The changes in cognition combined with the age-related changes in motor control may affect how older adults use information to learn new motor skills.

Motor learning research on young adults has identified many variables such as augmented feedback that enhance learning processes[1,2,5-8]. Although there are a limited number of studies on older adults, the available results suggest that despite the changes associated with aging, older adults benefit from augmented feedback similarly to young adults[9-12].

Wishart et al.[13] conducted a study investigating the effects of age and the role of visual augmented feedback in the acquisition of a new bimanual coordination pattern. Young and older subjects were randomly assigned to receive either concurrent or terminal timing of feedback. The concurrent timing of feedback refers to augmented feedback that is given while the movement is in progress; the terminal timing to augmented feedback that is given after the skill has been performed. Both young and older adults benefited from the concurrent condition, but older adults gained more than young adults did, relative to the terminal condition. The results suggest that when learning bimanual coordination patterns, older adults are more sensitive to the availability of concurrent visual information, i.e. older adults did not benefit from augmented feedback similarly to young adults.

The study by Wishart et al.[13] raised the question of whether their deviating findings were specific for the acquisition of a new bimanual coordination pattern. The above-mentioned previous studies[9-12] all involved the learning of motor tasks using only the dominant hand, not a bimanual coordination task.

Augmented feedback is usually implemented as concurrent augmented feedback, which might result in the development of a dependency on the availability of feedback as indicated by the guidance hypothesis. This hypothesis indicates that the role of augmented feedback in learning is to guide performance to be correct during practice[14]. However, if it is provided too frequently, it causes the subject to develop a dependency on its availability, and therefore to perform poorly when it is not available. So, practice with concurrent augmented feedback is beneficial for the immediate performance, but might not be for the learning of motor skills. Terminal augmented feedback can be effective in most skill learning situations[15].

In the present study, we compared young and older subjects regarding their ability to use visual augmented feedback to learn a new unilateral motor task. The task selected for the present study was to lower muscle activity as measured by surface electromyography (sEMG) while performing a gross motor task. This task was based on a treatment program used on groups of patients with work-related musculoskeletal pain[16,17]. Subjects were provided with a visual EMG signal, which varied in proportion to the electrical activity recorded from a target muscle. Subjects could then monitor the target muscle while attempting, through trial and error, to decrease muscle activity. Lowering muscle activity while actually using the same muscle to perform a gross motor task is physiologically possible, but difficult to perform for many subjects, leaving room for improvement with muscle re-education procedures. Research by Voerman et al.[18] has indicated that subjects performing this muscle relaxation task profited from a sensory feedback (myofeedback) training procedure.

Hermens and Hutten[16], Vollenbroek-Hutten et al.[17], and Faucett et al.[19] found similar results in groups of patients with work-related musculoskeletal pain receiving myofeedback training. The results indicated that the use of myofeedback can result in a change of muscle activation pattern, so apparently it assists in making subjects aware of their muscle activation.

The first purpose of the present study was to examine whether concurrent or terminal timing of augmented feedback is most effective in facilitating motor skill learning. Based on the understanding of the detrimental guiding role of augmented feedback on learning, it was expected that by providing terminal instead of concurrent augmented feedback, the dependence on augmented feedback would decrease, and the learning of motor skills would improve, i.e. lower muscle activity while performing gross motor task.

The second purpose of this study was to examine the combined effect of age and timing of augmented feedback on motor skill learning. Separate groups of the feedback timing conditions were formed for both young and older adults to examine age-related effects on motor learning. We hypothesized that both age categories would learn the new motor task. However, given the cognitive and performance changes associated with aging, the young adults were expected to achieve a better level of performance than the older adults (lower muscle activity). In addition, based on previous findings suggesting that older adults benefit from the learning variables similarly to young adults, it was expected that the guidance hypothesis is also valid for older adults. In other words, the timing of augmented feedback has similar learning effects on both young and older adults.

Methods

Design and subjects

Healthy, able-bodied subjects within two age categories (young adults: 20-35 years; and older adults: 55-70 years) were selected by means of a checklist concerning the health status of the subjects. To be included in the study, subjects had to be free of any history of upper extremity pathology. Subjects were excluded if they suffered from blindness or cognitive impairments (e.g. dementia). Recruitment of the young adults was performed under the employee-population (also graduate students) of Roessingh Research and Development and the University of Twente in Enschede, the Netherlands. Older adults were recruited among the wide circle of acquaintances of the researchers. The study was approved by the Roessingh ethics committee. All subjects signed an informed consent.

In total, 32 subjects (16 young and 16 older adults) were recruited for the study. The subjects of both age categories were randomly assigned to two groups (A or B) with the restriction that the groups were balanced for gender. Eight subjects were assigned to each group (3 males and 5 females per group). The two groups were differentiated in terms of timing of augmented feedback that provided subjects with information related to the muscle activity. Subjects had no prior experience with the experimental task and were not aware of the specific purposes of the study. Demographic characteristics of the subject population for both age categories are listed in Table 1.

Table 1. Demographic characteristics of the subject population

Characteristics	Young adults	Older adults
N	16	16
Sex (male / female)	6 / 10	6 / 10
Age (year)[a]	27.1 (4.5)	64.3 (8.8)
Weight (kg)[a]	68.7 (6.3)	80.1 (15.5)
Length (cm)[a]	177.1 (8.7)	173.2 (9.5)
Body Mass Index (kg / m^2)[a]	21.9 (1.8)	26.5 (3.6)
Dominant hand (right / left)	13 / 3	14 / 2

[a]mean (standard deviation)

Surface electromyographic (sEMG) detection

sEMG was recorded from the upper trapezius muscle of the dominant side. Its superficial location makes the trapezius muscle highly suitable for sEMG recording and feedback applications[20]. Before electrode placement, the skin was prepared by cleaning it with alcohol. Adhesive surface electrodes (inter-electrode distance 2.5 cm) were placed two cm laterally to the midpoint between cervical 7 and the lateral end of the acromion[21]. The position of the electrodes was marked with a permanent marker to ensure identical placement of the electrodes during measurements on different days.

The sEMG signal was amplified (15X), digitized (22 bits ADC), and smooth rectified with removal of the low frequency components. Sample frequency was 512 Hz and the signal was band pass filtered between 30 and 250 Hz. Embedded software provided the root mean square (RMS). The system was connected with a computer, and data were stored for off-line analysis.

Task and procedure

Subjects were seated behind a table in a chair without arm support. The height of the table and the chair were then adjusted so that elbow flexion of the dominant arm was within a range of 90-95 degrees when the upper arm was hold along the body with the forearm placed on the table. An angle smaller than 90 degrees would cause undesired trapezius activation due to elevation of the shoulder when moving the forearm and hand above the table. A computer monitor was positioned approximately 50 cm directly in front of the subjects.

Subjects performed a unilateral gross motor task in which they had to move their dominant arm / hand continuously by performing a ‘bottles-in-a-case’ task. Herewith, a bottle (with a weight of 160 g) must be replaced inside a case. The hand starts on the table, then grabs the bottle in the case and moves the bottle to the other side of the case. After this, the hand returns to the table and again replaces the bottle. The pace of the arm / hand movement (88 marks per min) was kept constant with the use of a metronome[22]. The goal of the task is to try and keep the trapezius muscle activity as low as possible during the motor task. Subjects were provided with visual myofeedback (raw EMG signal on the computer monitor) about their trapezius muscle activity. Besides a postural and supporting function, the trapezius muscle is important for the adjustment of the scapula during elevation of the upper arm, and it prevents from downward dislocation of the humerus[23].

The 32 selected subjects were randomly assigned to two feedback timing conditions. The conditions were differentiated in terms of concurrent and terminal timing of augmented feedback:

1. **Concurrent augmented feedback**. Visual myofeedback was provided immediately during the trial by means of displaying the raw EMG signal.
2. **Terminal augmented feedback**. Visual myofeedback was provided delayed (10 s) after the trial by means of displaying the recorded EMG signal from the prior trial.

sEMG recordings started with four reference contractions of the upper trapezius muscle performed according to the guidelines of Mathiassen et al.[24]. These reference contractions were followed by three tasks of one min without myofeedback to determine baseline activity. Subjects were instructed that they had to perform the task with the upper extremity (especially the dominant shoulder) as relaxed as possible with the non-dominant arm resting on the table. Subsequently, subjects performed the 1-min task 15 times with myofeedback. In between each measurement, there was a rest period of one min to prevent subjects from muscle overload. Subjects were instructed that they had to discover a way of performing the task that would result in the lowest muscle activity (shown on the computer monitor). Again, the non-dominant arm was resting on the table. These 15 tasks are considered the acquisition phase. Three 1-min tasks without myofeedback were performed twice to study retention: after 10 min (short-term retention) and after one week (long-term retention). Instructions were identical as those given during baseline measurement. The retention trials after one week (again preceded by a reference measurement) were measured on the same part of the day (morning or midday) as the acquisition trials. The retention trials were implemented to differentiate the effect augmented feedback may have on the more permanent changes in a motor skill from the transient changes in performance that may be observed during the acquisition phase of the study.

The myofeedback training procedure had a comparable amount of practice (and subsequent myofeedback exposure) to the study by Voerman et al.[18] in which subjects actually learned to lower their muscle activation level while performing a gross motor task.

Data analysis

Learning muscle relaxation was defined as a decrease in trapezius muscle activity expressed in sEMG outcome parameter root mean square (RMS, in μV). sEMG was continuously recorded during baseline, acquisition, and retention trials, and after the removal of artifacts, the RMS values were calculated over a period of 40 s within the 1-min trials (first and last 10 s were neglected because of possible starting and ending effects). This resulted in three baseline values, 15 acquisition values, and two times three retention values of RMS. These values were subsequently averaged resulting in one value for baseline, one per three acquisition trials, and one for each retention measurement per subject.

The RMS values during the reference contractions were computed for the middle 10 s of each reference contraction[24], and the mean value was used for normalization. This means that RMS values during baseline, acquisition, and retention trials were expressed as percentages of this mean reference value (RMS *relative* = RMS trial / RMS reference * 100%). After this normalization procedure, individual values were averaged to obtain group results.

Statistical analysis

The dependent measure RMS*rel* was analyzed in a two sample *t* test for baseline measurements comparing the two feedback timing conditions separately for the age categories. This was done to check the randomization procedure for both young and older adults.

With regard to the first purpose of the present study, the acquisition data were analyzed using a two (feedback conditions) x six (baseline and acquisition blocks) analyses of variance (ANOVA) with repeated measures on the last factor. Retention data were analyzed with a similar design, except that there were only two trial blocks (short- and long-term retention). These analyses were done separately for the age categories young and older adults. With regard to the second purpose of this study, the acquisition and retention data were analyzed using a two (age categories) x six (baseline and acquisition blocks) ANOVA with repeated measures on the last factor. These analyses were done separately for the feedback timing conditions concurrent and terminal. The Greenhouse-Geisser correction factor for degrees of freedom was used in all ANOVAs. Alpha was set at .05 for all statistical tests.

Results

Baseline phase

The initial performance level on the relaxation task was compared between the two feedback timing conditions separately for the age categories by conducting a two sample *t* test for the baseline phase. This analysis did not result in a statistical significant difference for young adults (95% confidence interval (CI) from -0.26 to 0.11, p = .41) and for older adults (95% CI from -0.17 to 0.31, p = .55). Therefore, randomization was accepted as satisfactory for both age categories.

Acquisition phase

The dependent measure RMS*rel* is plotted as a function of feedback timing conditions and blocks in Figure 1.

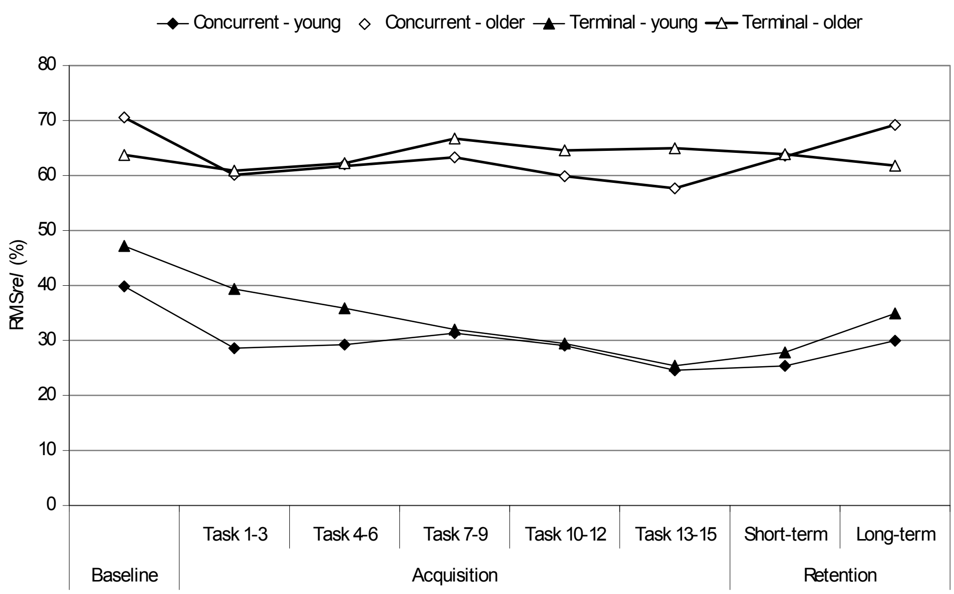

Figure 1. RMS*rel* as a function of blocks for baseline, acquisition, and retention

The first part of the analysis concerned the 2-way ANOVA (feedback condition x block) for repeated measures on the second factor. This was done separately for the age categories young and older adults. Concerning the young adults, a statistical significant main effect for block was found (F = 7.82, p = .000). No statistical significant main effect for feedback condition (F = 0.24, p = .63) and no interaction effect (feedback condition x block) was found (F = 1.00, p = .39). Concerning the older adults, no statistical significant effects were found on main effect for block (F = 1.19, p = .33) main effect for feedback condition (F = 0.02, p = .90) and interaction effect (F = 1.11, p = .35).

The second part of the analysis consisted of the 2-way ANOVA (age category x block) for repeated measures on the second factor, performed separately for the feedback timing conditions concurrent and terminal. The concurrent condition showed a statistical significant main effect for block (F = 3.24, p = .04) and for age category (F = 9.53, p = .01). No statistical significant interaction effect (age category x block) was found (F = 0.03, p =.98). The terminal condition only showed a statistical significant main effect for age category (F = 6.40, p = .02). No statistical significant effects were found on main effect for block (F = 2.01, p = .16) and interaction effect (F = 3.15, p = .06).

Retention phase

Again, two parts of analysis were performed. The first part that was performed separately for both age categories concerned the 2-way ANOVA (feedback condition x block) for repeated measures on the second factor. For young adults, no statistical significant effects were found on main effect for block (F = 2.20, p = .16), main effect for feedback condition (F = 0.31, p = .56), and interaction effect (F = 0.10, p = .75); and for older adults on main effect for block (F = 0.24, p = .63), main effect for feedback condition (F = 0.09, p = .77), and interaction effect (F = 1.17, p = .30).

The second part of the analysis consisted of the 2-way ANOVA (age category x block) for repeated measures on the second factor, performed separately for the feedback timing conditions. The feedback timing conditions only showed a statistical significant main effect for age category; concurrent condition (F = 21.38, p = .000) and terminal condition (F = 8.00, p = .01). For concurrent condition, no statistical significant effects were found on main effect for block (F = 1.44, p = .25) and interaction effect (F = 0.02, p = .91); and for terminal condition on main effect for block (F = 0.62, p = .45) and interaction effect (F = 2.06, p = .17).

Discussion

The present study compared the effects of timing of myofeedback on learning muscle relaxation in two age categories (young and older adults). Due to the small simple size used in this study, we must be cautious when interpreting the data. This is especially the case in the group of older adults since aging is a highly personal process, with individuals possibly being different from each other[4].

As expected and indicated by the significant main effect for block during baseline and acquisition, young adults succeeded to lower their muscle activity while performing the gross motor task, i.e. they improved their performance. In contrast, older adults did not improve their performance of the relaxation task. No statistical significant main effect for block was found. The latter result is in contrast to the findings of Hermens and Hutten[16]. Their study indicated that the use of myofeedback can result in a change of trapezius muscle activation pattern in patients with work-related musculoskeletal pain. Palmerud et al.[25] showed that a redistribution of activity takes place as the subject endeavors to minimize the signal level from the trapezius muscle. We expected that healthy subjects were also able to change this muscle activation pattern in the completion of a given task as was reflected in the study by Voerman et al.[18]. Apparently, this was just the case for young adults and not older.

To explain this lack of improvement in older adults, it can be argued that the provided information about the muscle activity (myofeedback) used in the present study was too complicated for older adults to interpret. The age-related changes in cognitive processing[3] possibly hindered them to comprehend this specific information and use it to improve their performance. In addition to this argument, Swinnen et al.[26] argued that learning new motor skills in older adults is more susceptible to the influence of previous learning than it is for younger adults. Old habits, over-learned tasks, and natural preferred or automated processes seem particularly difficult for older adults to inhibit when trying to perform tasks in which these processes must be suppressed.

The first purpose of the present study was to examine whether concurrent or terminal timing of augmented feedback is most effective in facilitating motor skill learning. Regardless of age, no significant interaction effects were found between the two feedback timing conditions on both acquisition and retention phase. These results do not support the predictions based on the guidance hypothesis, according to which the dependence on augmented feedback can be decreased by reducing the availability of the feedback[14,15].

In accordance with the present results, Wishart and Lee[12] encountered a similar failure to replicate previous findings based on the guidance hypothesis. They found for both young and older adults that relative frequency conditions of augmented feedback do not have a differential influence on learning a motor skill during any phase of the experiment. Also, Mulder and Hulstijn[27] showed no difference between the effect of concurrent and terminal myofeedback in learning voluntary abduction of the big toe. They suggested that the timing of feedback is not the main factor in myofeedback, but rather the specificity of the information.

In the present study, the lack of differences between the two feedback timing conditions could be caused by the response complexity of the task. The relaxation task used in this study is very different from the tasks that were typically used in motor learning research[1,2]. Motor learning research usually concerns simple, one-dimensional tasks that generally require little response complexity. The task in this study requires an interaction between more influential factors like actual performance factors (posture, placement of the bottle, and pace of the movement according to the metronome) and physiological factors (stress, muscle fatigue, and energy level). In accordance with this, Swinnen[8] challenged in a review the current understanding of the detrimental guiding role of augmented feedback on motor learning in that the role of feedback may be quite task (and subject) specific.

The second purpose of the present study was to examine the combined effect of age and timing of augmented feedback on motor skill learning. Regardless of the timing condition of myofeedback, young subjects performed the task with lower muscle activity than older adults both during the acquisition trials (when myofeedback was provided) and the retention trials (when myofeedback was withheld) as illustrated in Figure 1 and by the significant main effects for age category. In accordance with the present results, Laursen et al.[28] found in their study higher levels of EMG activity in older adults compared to young adults. Their explanation was that the changed motor control in older adults necessitates an increased muscle activity. The higher levels of EMG activity indicate a relatively higher effort of the older adults. Considering that the absolute mechanical load was very similar for both age categories, a decrease in mechanical output of the muscles might contribute to this finding.

Based on previous results of studies examining the combined effect of age and learning variables on motor skill learning[9-12], we expected no differences in the way motor learning was facilitated by the variable timing of augmented feedback for both age categories. The absence of any interactions of age with the timing conditions supports the contention that older subjects used the concurrent and terminal timing conditions in a similar way as young adults. However, since older adults did not improve their performance throughout the experiment, this finding should be interpreted with caution. The chosen task did not illustrate the effects of timing of augmented feedback for the older adults, i.e. either timing condition was equally helpful to young adults, while neither was helpful for older adults.

From motor learning research, there is evidence that as the task complexity increases, the differences in motor performance between young and older adults increase[29]. It is possible that a more complex motor task (like the specific tasks used in the present study and in the study by Wishart et al.[13]) would elucidate the age-related changes in the use of learning variables. Further research is needed to examine the role of augmented feedback on the learning of motor skills in older adults, particularly as it relates to the complexity of the specific motor tasks. Perhaps using another less complicated type of feedback, older adults are able to improve the relaxation task as presented in this study. The impact of the present study on the use of myofeedback systems – as used by Hermens and Hutten[16] – is that the treatment program should be carefully evaluated (and possibly adjusted) when treating older patients to increase their level of muscle rest.

References

1. Magill, R. A. (2001). *Motor learning: concepts and applications*. 6th ed. New York: McGraw-Hill.
2. Schmidt, R. A., & Lee, T. D. (1999). *Motor control and learning: a behavioural emphasis*. 3rd ed. Champaign: Human Kinetics.
3. Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging*. Hillsdale: Lawrence Erlbaum Associates.
4. Spirduso, W. W. (2005). *Physical dimensions of aging*. 2nd ed. Champaign: Human Kinetics.
5. Mulder, T., & Hulstijn, W. (1984). Sensory feedback therapy and theoretical knowledge of motor control and learning. *American Journal of Physical Medicine, 63(5),* 226-244.
6. Newell, K. M. (1991). Motor skill acquisition. *Annual Review of Psychology, 42,* 213-237.
7. Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: a review and critical reappraisal. *Psychological Bulletin, 95(3),* 355-386.
8. Swinnen, S. P. (1996). Information feedback for motor skill learning: a review. In H. N. Zelaznik (Ed.), *Advances in motor learning and control* (pp. 37-66). Champaign: Human Kinetics.
9. Carnahan, H., Vandervoort, A. A., & Swanson, L. R. (1996). The influence of summary knowledge of results and aging on motor learning. *Research Quarterly for Exercise and Sport, 67(3),* 280-287.
10. Swanson, L. R., & Lee, T. D. (1992). Effects of aging and schedules of knowledge of results on motor learning. *Journal of Gerontology: Psychological Sciences, 47(6),* 406-411.
11. Wiegand, R. L., & Ramella, R. (1983). The effect of practice and temporal location of knowledge of results on the motor performance of older adults. *Journal of Gerontology, 38(6),* 701-706.
12. Wishart, L. R., & Lee, T. D. (1997). Effects of aging and reduced relative frequency of knowledge of results on learning a motor skill. *Perceptual and Motor Skills, 84(3Pt1),* 1107-1122.
13. Wishart, L. R., Lee, T. D., Cunningham, S. J., & Murdoch, J. E. (2002). Age-related differences and the role of augmented visual feedback in learning a bimanual coordination pattern. *Acta Psychological, 110(2-3),* 247-263.
14. Park, J. H., Shea, C. H., & Wright, D. L. (2000). Reduced-frequency concurrent and terminal feedback: a test of the guidance hypothesis. *Journal of Motor Behavior, 32(3),* 287-296.
15. Winstein, C. J., Pohl, P. S., Cardinale, C., Green, A., Scholtz, L., & Waters, C. S. (1996). Learning a partial-weight-bearing skill: effectiveness of two forms of feedback. *Physical Therapy, 76(9),* 985-993.
16. Hermens, H. J., & Hutten, M. M. R. (2002). Muscle activation in chronic pain: its treatment using a new approach of myofeedback. *International Journal of Industrial Ergonomics, 30(3-4),* 325-336.
17. Vollenbroek-Hutten, M. M. R., Hermens, H. J., Voerman, G. E., Sandsjo, L., & Kadefors, R. (2004). Are changes in pain induced by myofeedback training related to changes in muscle activation patterns in patients with work-related myalgia? *European Journal of Applied Physiology, 8*.
18. Voerman, G. E., Sandsjo, L., Vollenbroek-Hutten, M. M. R., Groothuis-Oudshoorn, C. G., & Hermens, H. J. (2004). The influence of different intermittent myofeedback training schedules on learning relaxation of the trapezius muscle while performing a gross-motor task. *European Journal of Applied Physiology, 93(1-2),* 57-64.
19. Faucett, J., Garry, M., Nadler, D., & Ettare, D. (2002). A test of two training interventions to prevent work-related musculoskeletal disorders of the upper extremity. *Applied Ergonomics, 33(4),* 337-347.

20. Wærsted, M., & Westgaard, R. H. (1997). An experimental study of shoulder muscle activity and posture in a paper version versus a VDU version of a monotonous work task. *International Journal of Industrial Ergonomics, 19,* 175-185.
21. Hermens, H. J., Freriks, B., Merletti, R. et al. (1999). *European Recommendations for Surface ElectroMyography, Results of the SENIAM Project*. Enschede: Roessingh Research and Development.
22. Nederhand, M. J., IJzerman, M. J., Hermens, H. J., Baten, C. T., & Zilvold, G. (2000). Cervical muscle dysfunction in the chronic whiplash disorder grade II (WAD-II). *Spine, 25(15),* 1938-1943.
23. Basmaijan, J. V., & De Luca, C. J. (1985). *Muscles alive. Their functions revealed by electromyography*. 5th ed. Baltimore: Williams & Wilkins.
24. Mathiassen, S. E., Winkel, J., & Hägg, G. M. (1995). Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies: a review. *Journal of Electromyography and Kinesiology, 4,* 197-226.
25. Palmerud, G., Sporrong, H., Herberts, P., & Kadefors, R. (1998). Consequences of trapezius relaxation on the distribution of shoulder muscle forces: an electromyographic study. *Journal of Electromyography and Kinesiology, 8(3),* 185-193.
26. Swinnen, S. P., Verschueren, S. M., Bogaerts, H., Dounskaia, N., Lee, T. D., Stelmach, G. E. et al. (1998). Age-related deficits in motor learning and differences in feedback processing during the production of a bimanual coordination pattern. *Cognitive Neuropsychology, 15,* 439-466.
27. Mulder, T., & Hulstijn, W. (1985). Delayed sensory feedback in the learning of a novel motor task. *Psychological Research, 47,* 203-209.
28. Laursen, B., Jensen, B. R., & Ratkevicius, A. (2001). Performance and muscle activity during computer mouse tasks in young and elderly adults. *European Journal of Applied Physiology, 84(4),* 329-336.
29. Light, K. E., & Spirduso, W. W. (1990). Effects of adult aging on the movement complexity factor of response programming. *Journal of Gerontology, 45(3),* 107-109.

CHAPTER 7

General discussion

Demographic changes regarding the aging population places a considerable pressure on current health care resources because of the increasing number of elderly people that need some form of hearth care[1]. In order to reduce the burden on health care resources (e.g. therapists), the health care system is forced to innovate. Through the use of innovative technologies, elderly people may receive appropriate therapy at home. Here, the feedback by therapists is (partly) being replaced by augmented feedback provided by an interactive training device. Augmented feedback forms a critical aspect for the successful implementation of such technologies. Within this context, the present thesis is focused on the influence of age and augmented feedback on learning motor skills.

An overview on how augmented feedback is currently being used to train motor function in rehabilitation was presented in chapter 2 and 3. This framework will be discussed first as it was used to set up the three experiments performed in this thesis (chapter 4, 5, and 6). The main findings of these experiments will be discussed, together with the implications of these findings for motor learning research and rehabilitation practice. Finally, recommendations for further research are given.

General discussion

Augmented feedback is considered to be a potent variable affecting motor skill learning[2]. Since the re-acquisition of motor skills forms an important part of the total process of functional motor recovery, augmented feedback has implications for rehabilitation practice[3]. A review regarding the effects of therapeutic interventions using augmented feedback on motor function in rehabilitation patients was presented in chapter 2[4]. Here, the augmented feedback underlying a diversity of therapeutic interventions was provided by training devices (e.g. EMG biofeedback therapy and robot-assisted movement training using kinetic feedback) that were partly replacing the rehabilitation therapist. No firm evidence was found of the effectiveness regarding the use of augmented feedback to improve motor function. However, nine RCTs reported a difference in effectiveness between treatment groups in favor of the therapeutic intervention using augmented feedback, and 13 RCTs reported no difference between interventions. These findings implicate that training motor function by employing augmented feedback at least does not result in a negative outcome compared to training with the help of a therapist. This supports the feasibility of training patients at home, where a distance training application can adequately provide augmented feedback to the patient comparable to the direct presence of a therapist.

Promising applications for distance training aimed at the restoration of motor function were reviewed in chapter 3[5]. Most of the innovative training applications that were discussed in this chapter have not been (fully) incorporated into the health care system until yet. This is not surprising since these applications are relatively new, and well designed evaluation studies are lacking. All three training applications employed in the present thesis are based on these distance training applications.

Providing augmented feedback: a possible compensatory strategy

The changes in cognitive processing associated with aging cause a decline in task performance[6]. As people age and the speed of information processing decreases[7,8] individuals have to develop strategies to cope with these losses. Compensatory strategies are the subject of continued research in aging and human performance (e.g. Morgan et al.[9]). It is argued that a compensatory strategy could consist of the provision of additional information to the elderly subject. Indeed, when the ability of older adults to process task-intrinsic information may be compromised, and when – as a consequence – older adults may be more dependent on the available external information, augmented feedback becomes a relevant treatment tool. This implicates that older adults may compensate their declines in performance by using additional information.

Within this line of thought, experiment 1 in chapter 4 was performed to examine if providing external cues and/or augmented feedback actually helps older adults to compensate for their declines in task performance. Although the observed age-related decline in task performance was not fully compensated by providing the additional information, the results of this experiment indicated that adding external cues and augmented feedback indeed enhances the level of performance in both young and older adults. In other words, the cues and feedback offered the subjects a strategy to learn the increasing sequence of hand positions. This is in accordance with the results of earlier studies[10-12], and similar to the results of experiment 2 in chapter 4 and to the results of the kinetic study in chapter 5. In these studies, augmented feedback enabled the subjects to change the attempts on the subsequent trial, thus guiding the subject to a higher level of performance. However, providing augmented feedback did not improve task performance of the elderly subjects in the myofeedback study[13] (chapter 6). Here, older adults did not learn to lower their muscle activity by using myofeedback, i.e. the observed age-related decline in performance was not compensated.

Several related arguments can be put forward to explain this. Firstly, the provided information about the muscle activity (myofeedback) may have been too complicated for older adults to interpret. The age-related changes in cognitive processing[14] possibly hindered them to comprehend this specific information and to use it for improving their performance. Secondly, the complexity of the task is an important factor. The response of the relaxation task (while at the same time performing a gross motor task) required a complex interaction between actual performance factors (e.g. posture and pace of the movement) and physiological factors such as stress and muscle fatigue. This may have been too difficult for the older adults to accomplish, also considering older adults are more susceptible to the influence of previous learning than young adults. Old habits, over-learned tasks, and natural preferred or automated processes seem to be particularly difficult for older adults to inhibit when trying to perform tasks in which these processes must be suppressed. Thus, although several studies have indicated that providing augmented feedback is a successful compensatory strategy to decrease the age-related decline in task performance, the myofeedback study illustrates that this role of augmented feedback is subject as well as task specific.

Concerning the kinetic feedback study, the elderly subjects did not need augmented feedback to compensate for their decline in performance since no difference in the level of performance on the force-production task was detected (also at baseline level with no augmented feedback available). It was expected in all three studies performed in this thesis that young adults would outperform the older adults. The lack of age-related declines in performance therefore concerns a remarkable finding in the kinetic feedback study. Carnahan et al.[15] revealed a similar lack of age-related differences between age categories in their study, where subjects were required to learn a computer key-pressing task. One of their explanations was that the task may not have been complex enough to identify age-related differences. Previous research suggested that as task complexity increases, the difference between young and older adults also increases[16]. Compared to the other two tasks that were used in both studies, this explanation might also be valid here. Three different motor tasks were used in the three studies described in this thesis (sequential hand-movement task, isometric force-production task, and muscle relaxation task), all of which differed in response complexity. In comparison to the sequential and relaxation task, the force-production task concerns a relatively simple one-dimensional task that requires little response complexity. Concerning the sequential task, response complexity increases as the sequence becomes longer. And learning muscle relaxation while actually performing a gross motor task also requires a complex response. Indeed, an age-related decline in task performance was detected in both studies learning these relatively complex tasks. This contradicts to the results of the kinetic feedback study. This stresses the argument that it is the complexity of the task that determines whether performing the task will demonstrate an age-related decline in level of performance.

Motor learning research, until now, has focused primarily on young, healthy subjects learning new motor skills[17-21]. These studies indicated that the use of augmented feedback has a relevant influence on the obtained learning effects[2,3,22-24]. Research on aging and the learning of motor skills has not received much attention. There is a practical need for more research in this area. Older adults do learn new motor skills – as a part of new job training, recreational pursuits, and rehabilitation therapy. A better understanding on how the elderly people learn (and relearn) motor skills is needed to be able to facilitate the performance of these activities. Hence, a relevant question in this concerns how older adults use augmented feedback. For example, do older adults use augmented feedback in a similar way as young adults?

The results of this thesis indeed seem to point out that older adults use augmented feedback in a similar way as young adults. No evidence was found in any of the three studies that aging influences the way in which augmented feedback facilitates motor skill learning. These results are supported by the limited evidence available[15,25-27]. This may implicate that the guidelines derived from our current knowledge on motor learning[17-21] – as related to the use of different types of augmented feedback such as form, content, and timing – can also be employed by the elderly subjects. However, caution should be taken when adopting motor learning guidelines from young to older adults. As it turns out in the present thesis, guidelines of motor learning are misleading and oversimplified without reference to subject and task characteristics.

It should be noted that the processes underlying the motor learning effects may still differ between young and older adults, although both age categories appear to use augmented feedback in a similar way. For example, older adults may need more effort – as a compensatory strategy – to accomplish a similar result as their young counterparts. This is even enhanced by the fact that the variability between older subjects is much greater than between young subjects[30], i.e. individuals age at different rates and to different degrees.

Implications for rehabilitation practice and further research

The implications for learning motor skills are almost totally derived from motor learning experiments with healthy, young adults. Although rehabilitation patients have to learn motor skills, they are often not young and never healthy. These patients suffer not only from motor problems, but also from a number of cognitive and behavioral problems, which have a severe impact on the learning abilities of these patients[31]. Direct translation of the results of motor learning experiments to therapeutic intervention should therefore take place with great care and some hesitation until the proper clinical studies have been conducted.

Indeed, few studies have attempted to examine the influential role of augmented feedback on the re-acquisition of motor skills, i.e. focusing on the specific feedback characteristics of the therapeutic interventions that were used to improve motor function. Saladin et al.[32] investigated the effects of reduced relative frequency of augmented feedback on motor learning in stroke patients and compared this to an age-matched control group. The results indicated that both groups benefited from reducing the relative frequency of augmented feedback in learning an isometric force-modulation task, similar to the one used in chapter 6. This study may therefore suggest that the neuropathology of (unilateral) stroke does not affect the way in which augmented feedback facilitates motor skill learning since reducing the relative frequency of augmented feedback has previously shown to be beneficial for motor learning in healthy adults[17-20,33]. In another study by Guadagnoli et al.[34] examining the effects of reduced relative frequency of augmented feedback in Parkinson's disease patients (PD), the results indicated that PD patients do not react similarly on reducing the relative frequency of augmented feedback as their age-matched controls. In contrast to the control group and previous findings in motor learning[17-20,32], PD patients learned the imposed simple timing task best without reducing the relative frequency of augmented feedback.

Obviously, a lot of research still needs to be performed to determine how different rehabilitation patients respond to different types of augmented feedback in the re-acquisition of motor skills. The current knowledge on motor learning research can be used as a starting point for translating basic research findings to rehabilitation practice. The present thesis may play a modest role in this translation process because it examined the age-matched control groups of most rehabilitation populations. As pointed out in both reviews (in chapter 3 and 4 of this thesis), the target population of the rehabilitation practice generally consists of an elderly group of people (at least 50 years of age). The experiments in this thesis have been performed with a group of people within a comparable age category; healthy subjects between the age of 55 and 70 years (in comparison to the young adults of 20 to 35 years of age).

Some final thoughts about learning

The present thesis supports the feasibility of training people from the convenience of their own homes. Distance training applications with the use of augmented feedback may replace the direct presence of the therapist. By focusing on the learning effects of different types of augmented feedback, this thesis contributes to the future implementation of such distance training programs in rehabilitation practice. It should however be noted that, besides augmented feedback, other aspects have a relevant influence on the learning (and relearning) of motor skills. One of those aspects concerns the variability of practice[17,31]. Practice variability refers to a variety of movement and context characteristics, which the person experiences while practicing the task. To improve the generalization value of the training, the variability of practice should be increased. A second aspect concerns the design of the learning situation[31]. The learning context should be structured in such a way that it contains a large number of elements identical to the transfer situation. It is a challenge for further research on distance training to recognize not only the influential role of augmented feedback – as was done in the present thesis – but also the importance of exercise variability and context of the learning situation.

References

1. Lloyd-Sherlock, P. (2000). Population ageing in developed and developing regions: implications for health policy. *Social Science & Medicine, 51(6),* 887-895.
2. Newell, K. M. (1991). Motor skill acquisition. *Annual Review of Psychology, 42,* 213-237.
3. Winstein, C. J. (1991). Knowledge of results and motor learning – implications for physical therapy. *Physical Therapy, 71(2),* 140-149.
4. Dijk, H. van, Jannink, M. J. A., & Hermens, H. J. (2005). Effect of augmented feedback on motor function of the affected upper extremity in rehabilitation patients: a systematic review of randomized controlled trials. *Journal of Rehabilitation Medicine, 37(4),* 202-211.
5. Dijk, H. van, & Hermens, H. J. (2004). Distance training for the restoration of motor function. *Journal of Telemedicine and Telecare, 10(2),* 63-71.
6. Spirduso, W. W. (2005). *Physical dimensions of aging*. 2nd ed. Champaign: Human Kinetics.
7. Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103(3),* 403-428.
8. Welford, A. T. (1984). Between bodily changes and performance: some possible reasons for slowing with age. *Experimental Aging Research, 10(2),* 73-88.
9. Morgan, M., Philips, J. P., Bradshaw, J. L., Mattingley, J. B., Iansek, R., & Bradshaw, J. A. (1994). Age-related motor slowness: simply strategic? *Journal of Gerontology: Medical Sciences, 49,* M133-M139.
10. Janelle, C. M., Champenoy, J. D., Coombes, S. A., & Mousseau, M. B. (2003). Mechanisms of attentional cueing during observational learning to facilitate motor skill acquisition. *Journal of Sports Sciences, 21(10),* 825-238.
11. Mulder, T., & Hulstijn, W. (1985). Delayed sensory feedback in the learning of a novel motor task. *Psychological Research, 47,* 203-209.
12. Swinnen, S. P., Verschueren, S. M., Bogaerts, H., Dounskaia, N., Lee, T. D., Stelmach, G. E. et al. (1998). Age-related deficits in motor learning and differences in feedback processing during the production of a bimanual coordination pattern. *Cognitive Neuropsychology, 15,* 439-466.
13. Dijk, H. van, & Hermens, H. J. Effects of age and timing of augmented feedback on learning muscle relaxation while performing a gross motor task. *American Journal of Physical Medicine & Rehabilitation*.
14. Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging*. Hillsdale: Lawrence Erlbaum Associates.
15. Carnahan, H., Vandervoort, A. A., & Swanson, L. R. (1996). The influence of summary knowledge of results and aging on motor learning. *Research Quarterly for Exercise and Sport, 67(3),* 280-287.
16. Light, K. E., & Spirduso, W. W. (1990). Effects of adult aging on the movement complexity factor of response programming. *Journal of Gerontology, 45(3),* 107-109.
17. Magill, R. A. (2001). *Motor learning: concepts and applications*. 6th ed. New York: McGraw-Hill.
18. Proctor, R. W., & Dutta, A. (1995). *Skill acquisition and human performance*. Thousand Oaks: Sage.
19. Rose, D. J., & Christina, R. W. (2006). *A multilevel approach to the study of motor control and learning*. 2nd ed. San Francisco: Pearson Education Inc.
20. Schmidt, R. A., & Lee, T. D. (1999). *Motor control and learning: a behavioural emphasis*. 3rd ed. Champaign: Human Kinetics.
21. Wickens, C. D., & Hollands, J. G. (1999). *Engineering psychology and human performance*. 3rd ed. Upper Saddle River: Prentice-Hall Inc.

22. Mulder, T., & Hulstijn, W. (1984). Sensory feedback therapy and theoretical knowledge of motor control and learning. *American Journal of Physical Medicine, 63(5),* 226-244.
23. Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: a review and critical reappraisal. *Psychological Bulletin, 95(3),* 355-386.
24. Swinnen, S. P. (1996). Information feedback for motor skill learning: a review. In H. N. Zelaznik (Ed.), *Advances in motor learning and control* (pp. 37-66). Champaign: Human Kinetics.
25. Wishart, L. R., & Lee, T. D. (1997). Effects of aging and reduced relative frequency of knowledge of results on learning a motor skill. *Perceptual and Motor Skills, 84(3Pt1),* 1107-1122.
26. Swanson, L. R., & Lee, T. D. (1992). Effects of aging and schedules of knowledge of results on motor learning. *Journal of Gerontology: Psychological Sciences, 47(6),* 406-411.
27. Wiegand, R. L., & Ramella, R. (1983). The effect of practice and temporal location of knowledge of results on the motor performance of older adults. *Journal of Gerontology, 38(6),* 701-706.
28. Wishart, L. R., Lee, T. D., Cunningham, S. J., & Murdoch, J. E. (2002). Age-related differences and the role of augmented visual feedback in learning a bimanual coordination pattern. *Acta Psychological, 110(2-3),* 247-263.
29. Park, J. H., Shea, C. H., & Wright, D. L. (2000). Reduced-frequency concurrent and terminal feedback: a test of the guidance hypothesis. *Journal of Motor Behavior, 32(3),* 287-296.
30. Birren, J. E., & Schaie, K. W. (2001). *Handbook of the psychology of aging*. 5th ed. New York: Academic Press.
31. Mulder, T., & Hochstenbach, J. B. (2003). Motor control and learning: implications for neurological rehabilitation. In R. J. Greenwood (Ed.), *Handbook of neurological rehabilitation* (pp. 143-157). New York: Psychology Press.
32. Saladin, L. S., Baghdady, M., Nichols, L, & Logan, S. (1994). The effects of reduced relative frequency of feedback on motor learning in stroke patients. *Physical Therapy, 74(5),* S122.
33. Winstein, C. J., & Schmidt, R. A. (1990). Reduced frequency of knowledge of results enhances motor skill learning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 16,* 677-691.
34. Guadagnoli, M. A., Leis, B., Gemmert, A. W. van, & Stelmach, G. E. (2002). The relationship between knowledge of results and motor learning in Parkinsonian patients. *Parkinsonism & Related Disorders 9(2),* 89-95.

Summary

Learning motor skills is fundamental to human life. One of the most critical variables affecting motor learning, aside from practice itself, is augmented feedback (performance-related information). Although there is abundance of research on how young adults use augmented feedback to learn motor skills, little is known about how older adults use augmented feedback. The aim of this thesis (described in **chapter 1**) is to obtain a better understanding of the influence of age and augmented feedback on motor skill learning.

A framework is presented in chapter 2 and 3 on how different types of augmented feedback are currently being used in rehabilitation practice. This framework has been used to set up three different experiments on form (how?), content (what?), and timing (when?) of augmented feedback (presented in chapter 4, 5, and 6, respectively). The effects of these different types of augmented feedback have been studied in relation to two different age categories (young and older adults).

The first step was to assess the available evidence regarding the effect of augmented feedback on motor function of the upper extremity in rehabilitation patients. The results of a systematic literature search are described in **chapter 2**. Twenty-six randomized controlled trials were included, of which nine RCTs reported a positive effect on arm function. Follow-up measurements were performed in eight trials, one of which reported a positive effect. Different therapeutic interventions using augmented feedback, i.e. electromyographic biofeedback, kinetic feedback, kinematic feedback, and knowledge of results, show no difference in effectiveness. No firm evidence is found of effectiveness regarding the use of augmented feedback to improve motor function of the upper extremity in rehabilitation patients.

In **chapter 3**, the literature is then reviewed on distance training for the restoration of motor function. Eleven articles met the criteria for inclusion and were divided into three general areas concerning the type of training in relation to motor functions – muscle / joint, balance, and cognition. Six articles were related to the level of training of muscle / joint functions, four to balance functions, and one to cognitive functions. The articles were graded according to the strength of scientific evidence they offered. The review reveals some promising applications of distance motor training such as virtual reality (VR) and robotic devices. The strength of evidence from these studies was however poor, probably because the used technology is relatively new. In contrast to the studies using VR and robotic devices, those using electromyographic (EMG) biofeedback showed a good to fair strength of scientific evidence. This can be explained by the substantial history of

research on the restoration of motor function through the use of EMG biofeedback techniques.

Two related experiments are described in **chapter 4** to explore if providing additional information can compensate for the age-related declines in performance on a sequential hand-position task. In experiment 1, adding external cues and/or augmented feedback indeed enhanced task performance in both young and older adults. The decline in performance found in the elderly subjects was not fully compensated, i.e. older adults receiving cues and feedback did not perform the task on a similar level as young adults without this information. In experiment 2, it was examined whether the age-related decline in performance can be further compensated by optimizing the way in which the additional information is presented. The impact of the form of external cues and augmented feedback was studied by using two modality conditions (visual; visual & auditory). The results indicate no differences between both form conditions. This was the case for both young and older adults.

The study described in **chapter 5** addresses the interaction between age and the informational content of feedback on the acquisition and retention of an isometric force-production task. Healthy subjects (30 young adults: 20 to 35 years; 30 older adults: 55 to 70 years) were randomly assigned to a certain feedback condition: knowledge of results or kinetic feedback. The results show no differences between young and older adults in the accuracy and consistency of motor performance (regardless of feedback condition). There were no interactions of age with any of the feedback-related variables. These findings suggest that the effects of augmented feedback on motor skill learning are similar in both young and older adults.

The objective in **chapter 6** is to examine the combined effect of age and timing of augmented feedback on learning muscle relaxation. Performing a gross motor task, subjects had to lower their trapezius muscle activity using the electromyographic signal as visual feedback. Healthy subjects (16 young adults: 20 to 35 years; and 16 older adults: 55 to 70 years) were randomly assigned to one of two timing conditions of feedback: concurrent (feedback was provided immediately during the trial) and terminal (feedback was provided delayed after the trial). The results indicate that young adults had a higher level of motor performance (lower muscle activity) compared to older adults (regardless of feedback condition). In contrast to young adults, older adults did not improve their performance throughout the experiment. There were no interactions of age with the timing conditions of myofeedback during acquisition and retention. Either timing condition of myofeedback was equally helpful to young adults in learning muscle relaxation, while neither was helpful for older adults.

In the general discussion in **chapter 7**, the main findings of this thesis, together with their implications for motor learning research and rehabilitation practice are discussed. The findings of the present thesis support the feasibility of training patients at home, i.e. a distance training application can adequately provide augmented feedback to the patient (comparable to the direct presence of a therapist). Providing additional information such as augmented feedback proofs to be a successful strategy to compensate for the observed declines in task performance of the elderly subjects. However, this thesis also reveals that the role of augmented feedback is quite subject and task specific. The findings of the three studies – using different motor tasks – all together suggest that it is the complexity of the task that determines whether performing the task will illustrate an age-related decline in level of performance. Furthermore, this thesis seems to point out that older adults use augmented feedback in a similar way as young adults. No evidence was found in any of the three studies that aging influences the way in which augmented feedback – as related to the form, content, and timing – facilitates motor skill learning. This may implicate that the guidelines derived from our current knowledge base of motor learning can be adopted to the elderly subjects. Guidelines can however be misleading and oversimplified without reference to subject and task characteristics, particularly as it relates to elderly subjects and rehabilitation patients.

Samenvatting

Het leren van motorische vaardigheden is essentieel voor ons bestaan. Bij het oefenen van de motorische vaardigheden is feedback (terugkoppeling van informatie) een van de meest bepalende factoren die het motorische leren beïnvloedt. Hoewel er veelvuldig onderzoek is gedaan naar hoe jongeren feedback gebruiken om motorische vaardigheden te leren, is er weinig bekend over hoe ouderen omgaan met feedback. Het doel van dit proefschrift (beschreven in **hoofdstuk 1**) is het verkrijgen van een beter begrip ten aanzien van de invloed van leeftijd en feedback op het leren van motorische vaardigheden.

In hoofdstuk 2 en 3 is een kader geschetst van verschillende types feedback die momenteel worden toegepast binnen de revalidatie praktijk. Uitgaande van dit kader is een drietal experimenten opgezet gericht op de vorm (hoe?), inhoud (wat?) en timing (wanneer?) van feedback (weergegeven in respectievelijk hoofdstuk 4, 5 en 6). De effecten van deze verschillende types feedback zijn bestudeerd in relatie tot twee verschillende leeftijdscategorieën (jongeren en ouderen).

De eerste stap bestond uit het verzamelen van beschikbare gegevens van eerder uitgevoerde studies ten aanzien van het effect van feedback op motorische functies van de bovenste extremiteit bij revalidatiepatiënten. Hiertoe is een literatuurstudie beschreven in **hoofdstuk 2**. Zesentwintig studies werden systematisch bekeken. Negen hiervan rapporteerden een positief effect op armfunctie. Nametingen werden uitgevoerd in acht studies waarvan één een positief effect rapporteerde. Verschillende therapeutische interventies gebruikmakend van feedback (elektromyografische biofeedback, kinetische feedback, kinematische feedback en knowledge of results) laten geen verschil zien in effectiviteit. Er is geen overtuigend bewijs gevonden ten aanzien van het gebruik van feedback om motorische functies van de bovenste extremiteit bij revalidatiepatiënten te verbeteren.

In **hoofdstuk 3** is vervolgens de literatuur aangaande training op afstand voor het herstel van motorische functies systematisch bekeken. Elf artikelen voldeden aan de inclusiecriteria en werden verdeeld in drie algemene aandachtsgebieden met betrekking tot het type training van motorische functies – spier / gewricht, balans en cognitie. Zes hiervan waren gerelateerd aan het trainen van spier / gewricht functies, vier aan balans en een aan cognitie. De artikelen werden beoordeeld naar de sterkte van het aangetoonde wetenschappelijke bewijs. De literatuurstudie laat enkele belovende applicaties zien van motorisch trainen op afstand zoals virtuele realiteit en robotische systemen. Echter de sterkte van het bewijs van deze studies was zwak. Waarschijnlijk werd dit veroorzaakt door het feit dat de gebruikte technologie relatief nieuw is. In tegenstelling tot de studies gebruikmakend van virtuele realiteit en robotische systemen lieten de studies die gebruikmaken van elektromyografische biofeedback wel sterk wetenschappelijk bewijs zien. Dit kan worden verklaard door de uitgebreide geschiedenis van onderzoek op dit gebied.

Twee aan elkaar gerelateerde experimenten zijn beschreven in **hoofdstuk 4** om te onderzoeken of het aanbieden van extra informatie de leeftijdsgerelateerde achteruitgang in het leren van een reeks handgebaren kan compenseren. In experiment 1 verbeterde de prestatie van zowel jongeren als ouderen door cues en/of feedback toe te voegen. De achteruitgang in prestatie bij ouderen werd echter niet geheel gecompenseerd; ouderen die extra informatie ontvingen in de vorm van cues en feedback presteerden nog steeds niet op het niveau van de jongeren die geen extra informatie ontvingen. In experiment 2 werd beoordeeld of de leeftijdsgerelateerde achteruitgang in prestatie verder gecompenseerd kon worden door de wijze waarop de extra informatie werd gepresenteerd te optimaliseren. De vorm van presenteren van de cues en feedback werd hierbij bestudeerd door gebruik te maken van condities met verschillende modaliteiten (visueel; visueel & auditief). De resultaten tonen geen verschil aan tussen beide condities. Dit gold voor zowel jongeren als ouderen.

De studie die is beschreven in **hoofdstuk 5** richt zich op de interactie tussen leeftijd en de inhoud van feedback bij het leren van een isometrische krachtproductie taak. Gezonde proefpersonen (30 jongeren: 20 tot 35 jaar; 30 ouderen: 55 tot 70 jaar) werden willekeurig toegewezen aan een bepaalde feedback conditie: knowledge of results of kinetische feedback. De resultaten laten geen verschillen zien tussen jongeren en ouderen in de nauwkeurigheid en consistentie van de motorische prestatie (ongeacht feedback conditie). Er bleken geen interacties te bestaan tussen leeftijd en één van de feedback variabelen. Deze resultaten suggereren dat de invloed van feedback op het motorische leren gelijk is voor zowel jongeren als ouderen.

De doelstelling in **hoofdstuk 6** is om het gecombineerde effect van leeftijd en de timing van feedback op het aanleren van spierontspanning te bestuderen. Proefpersonen moesten hun trapezius spieractiviteit verminderen terwijl zij een grof motorische taak uitvoerden. Hierbij konden zij gebruikmaken van het elektromyografische signaal als visuele feedback. Gezonde proefpersonen (16 jongeren: 20 tot 35 jaar; 16 ouderen: 55 tot 70 jaar) werden willekeurig toegewezen aan een van de twee timing condities van feedback: concurrent (feedback gedurende de taak) en terminaal (feedback na afloop van de taak). De resultaten tonen aan dat jongeren beter presteerden dan ouderen (ongeacht feedback conditie). In tegenstelling tot jongeren verbeterden de prestaties van de ouderen niet gedurende het experiment. Er bleken geen interacties te bestaan tussen leeftijd en de timing condities van feedback. Beide feedback-timing condities hielpen de jongeren bij het uitvoeren van de taak. Dit in tegenstelling tot de ouderen waarbij geen van de timing condities hielpen bij het verbeteren van de prestatie.

In de algemene discussie in **hoofdstuk 7** zijn de resultaten van dit proefschrift samen met de implicaties voor onderzoek naar het leren van motorische vaardigheden en de revalidatiepraktijk besproken. De resultaten van het huidige proefschrift ondersteunen de haalbaarheid om patiënten in de thuissituatie te trainen; een trainingstoepassing op afstand kan op een adequate wijze feedback geven aan de patiënt (vergeleken met de directe aanwezigheid van een therapeut). Het aanbieden van extra informatie zoals feedback blijkt een succesvolle strategie te zijn om de waargenomen achteruitgang in prestatie bij ouderen te compenseren. Dit proefschrift laat echter ook zien dat de rol van feedback zeer afhankelijk van persoon en taak is. De resultaten van alle drie de studies (gebruikmakend van drie verschillende motorische taken) suggereren dat de complexiteit van de taak bepaalt of ouderen een achteruitgang in prestatie zullen laten zien tijdens het uivoeren van deze taak. Dit proefschrift lijkt bovendien aan te tonen dat ouderen op dezelfde wijze gebruik maken van feedback als jongeren. In geen van de drie studies is bewijs gevonden dat het ouder worden invloed heeft op de wijze waarop feedback – gerelateerd aan vorm, inhoud en timing – het motorische leren verbetert. Dit zou kunnen betekenen dat de richtlijnen vanuit onderzoek naar het motorische leren vertaald kunnen worden naar ouderen. Richtlijnen kunnen echter misleidend en te vereenvoudigd zijn wanneer er niet gerefereerd wordt naar persoon en taak karakteristieken, met name gerelateerd aan de oudere personen en revalidatiepatiënten.

Dankwoord

Na het beëindigen van de verschillende fases van mijn promotieonderzoek is het moment gekomen om het proefschrift af te ronden. Terugkijkend op de afgelopen jaren is er in het kader van mijn onderzoek veel werk verzet. Het opzetten en uitvoeren van de experimenten, het verwerken van de data en het schrijven van de artikelen. Aansluitend hierop is de algemene discussie tot stand gekomen. Om mijn promotieonderzoek te kunnen doen en dit proefschrift te kunnen schrijven en voltooien heb ik van velen hulp en steun gehad. Reden om in het onderstaande diegenen te bedanken die mij bij dit alles hebben geholpen.

Allereerst alle lof voor mijn beide promotoren Hermie Hermens en Theo Mulder voor hun deskundige en prettige begeleiding. Met Hermie had ik veruit het meeste contact. Onze voortgangsbesprekingen – die frequenter werden naarmate het onderzoek verder vorderde – ging ik regelmatig met de nodige vragen en twijfels in. Vragen en twijfels over of ik de juiste richting had ingeslagen op zowel het gebied van het opzetten en uitvoeren van de experimenten als het schrijven van de artikelen. Tijdens deze besprekingen heb ik veel van je geleerd en ik hoop dat in de toekomst te mogen blijven doen. In het bijzonder heb ik veel geleerd van jouw inzicht en vermogen om snel en feilloos tot de kern van de zaak te kunnen komen. Bovendien heb je veel vertrouwen in mijn kunnen gesteld en liet jij mij altijd met een goed gevoel weer vertrekken. Met veel plezier denk ik dan ook aan onze besprekingen terug.

Theo is in een wat later stadium betrokken geraakt bij mijn promotietraject. Niettemin is ook deze samenwerking van grote invloed geweest op het onderzoek en ook daar denk ik met een goed gevoel aan terug. Ik vind dat jouw kennis en ervaring op het gebied van de bewegingsleer een belangrijke sturende werking heeft gehad op het onderzoek. In het bijzonder denk ik hierbij aan jouw voorstel om het leren bij ouderen centraal te stellen in de experimenten. Je was altijd zeer kritisch en je vertelde onomwonden waar het naar jouw mening op stond, hetgeen voor mij de nodige leermomenten heeft opgeleverd.

Mijn dank gaat tevens uit naar de overige leden van de promotiecommissie – de professoren Pieters, Verwey, Veltink, Postema, IJzerman en Spijkers – die allen tijd en energie hebben gestoken in het beoordelen van mijn proefschrift.

Zonder proefpersonen hadden de experimenten niet uitgevoerd kunnen worden. Sommigen hebben zelfs aan alle drie experimenten enthousiast meegewerkt. Collega's, familie, vrienden, bekenden en minder bekenden, allen hebben zich volledig ingezet. In het bijzonder verdienen mijn moeder Ineke en mijn schoonouders Jaap en Marijke hier aandacht voor het meewerken en het regelen van andere enthousiastelingen.

Natuurlijk wil ik ook stilstaan bij de collega's van Roessingh Research and Development. Ik kon altijd bij jullie terecht om te overleggen of even te kletsen. Zonder collega's te willen overslaan noem ik hier een aantal bij name: Diane, Inger, Leendert, Jos, Wil, Karin, en Sascha.

Arjan Stoter bedank ik voor de prettige samenwerking. Het was altijd erg nuttig en gezellig om met jou te brainstormen over het onderzoek. Ik hoop dat het je goed gaat de komende periode waarin jij ook je promotie gaat afronden.

Mijn familie en vrienden mogen hier natuurlijk niet ontbreken. Jullie hebben gezorgd voor de nodige afleiding en ontspanning gedurende de afgelopen periode. Michiel Jannink en Luuk Engbers wil ik hier graag noemen. Naar mijn mening is in de afgelopen jaren een bijzondere driehoeksverhouding ontstaan. Michiel in het oosten, Luuk in het westen, en ikzelf op-en-neer reizend er tussenin. Bedankt voor jullie steun. Daarnaast wil ik Gert Bergman bedanken voor zijn altijd aanwezige relativerende vermogen. Ik beschouw jullie alledrie als goede vrienden!

In de roerige eindfase van mijn promotieonderzoek waarin de discussie moest worden geschreven en veel overleg gepleegd moest worden met de promotoren – met de voortdurende gedachte of het proefschrift de toets der kritiek zou kunnen doorstaan – is er ook op het persoonlijke vlak nogal wat voorgevallen. Namelijk dat mijn opa en vader – die samen met mijn moeder, zus en broer veel voor mij betekenen – zijn komen te overlijden. Ook op die momenten en in de verdrietige periode erna heb ik enorm veel steun van jullie allemaal gekregen en kon ik op jullie allen terugvallen.

Lieve Nicole, met jou sluit ik dit dankwoord graag af. Onbeschrijfelijk wat jij voor mij betekent! Altijd volop vertrouwen in mijn kunnen. Bedankt hiervoor! Kus ook voor kleine Noa – ook al ben jij er nog maar net en begrijp jij nog niet helemaal waar het over gaat.

Allen, hartelijk dank!

Over de auteur

Henk van Dijk werd geboren op 11 mei 1977 in Wezep, gemeente Oldebroek. Na het volgen van de middelbare school op het toenmalige Carolus Clusius College te Zwolle begon hij in 1995 met de studie Bewegingswetenschappen aan de Rijksuniversiteit Groningen. Binnen deze studie koos hij voor de afstudeerrichting Arbeid en Gezondheid. Zijn afstudeerproject verrichtte hij bij de Dienst Vervoer en Ondersteuning te Veenhuizen - een facilitaire organisatie die belast is met het verlenen van vervoer en bijstand aan onderdelen van het Ministerie van Justitie. Hier ontwikkelde hij criteria voor een fysieke selectietest voor de medewerkers. Hij haalde zijn doctoraal in mei 2000.

Aansluitend op het behalen van zijn doctoraal begon hij als onderzoeks-medewerker bij Roessingh Research and Development te Enschede. Henk is na een periode waarin hij verschillende kortlopende projecten uitvoerde gestart met zijn promotieonderzoek binnen het ExO-Zorg project in oktober 2002. De hoofddoelstelling van het project Extramurale Ont-Zorgtechnologie is kennisontwikkeling inzake revalidatieprocessen 'op afstand', gericht op hoogwaardige training van het houdings- en bewegingsapparaat. Het ExO-Zorg project betreft een grootschalig project dat opgebouwd is uit meerdere werkpakketten. Henk zette zijn onderzoek op binnen het werkpakket dat zich richtte op het gebruik van feedback bij het aanleren van motorische vaardigheden. In maart 2006 promoveert hij op dit onderzoek.

Progress range

The following publications have also been published in the progress range by Roessingh Research and Development, Enschede the Netherlands. Copies can be ordered as long as available via info@rrd.nl.

1. Pot, J. W. G. A., Boer, H., Harten, W. H. van, Hermens, H. J., & Seydel, E. R.. Comprehensive Need-Assessment. Ontwikkeling van een meetinstrument voor zorgbehoeften en kwaliteitsbeoordeling door patiënten, Roessingh Research and Development, the Netherlands, September 1994, ISBN 90-25452-01-2.
2. Leerdam, N. G. A. van, & Hermens, H. J. Revalidatietechnologie in Euregio, Roessingh Research and Development, the Netherlands, July 1995, ISBN 90-75452-02-0.
3. Duda, L., Noort, L. O. van, Röseler, S., Greitemann, B. O. L., Harten, W. H. van, & Klazinga, N. S. Rehabilitation in Germany and the Netherlands, a comparison of two rehabilitation-systems, Roessingh Research and Development, the Netherlands, August 1995, ISBN 90-75452-03-9.
4. Hermens, H. J., Nenen, A. V., & Zilvold, G. Electrophysiological Kinesiology. Proceedings of the 11th congress of the International Society of Electrophysiologie and Kinesiology in Enschede, The Netherlands, Roessingh Research and Development, the Netherlands, October 1996, ISBN 90-75452-04-7.
5. Harten, W. H. van. Bouwen aan een kwaliteitssysteem in de revalidatiezorg. Een poging tot constructieve technology assessment van een kwaliteitssysteem in een gezondheids-zorginstelling, Roessingh Research and Development, the Netherlands, December 1997, ISBN 90-75452-07-1.
6. Baardman, G., & IJzerman, M. J. Design and evaluation of a hybrid orthosis for people with paraplegia, Roessingh Research and Development, the Netherlands, November 1997, ISBN 90-75452-08-X.
7. Hutten, M. M. R. Lumbar dynamometry: a useful method for assessment of patients with chronic low back pain?, Roessingh Research and Development, the Netherlands, November 1999, ISBN 90-75452-13-6.
8. Salm, A. van der, Harten, W., H. van, & Maathuis, C. G. B. Ketenkwaliteit Cerebrale Parese Zorg. Een beschrijving van de cerebrale parese zorg en mogelijke verbeteringen hierin, Roessingh Research and Development, the Netherlands, April 2001, ISBN 90-75452-19-5.
9. Nederhand, M. J. Muscle activation patterns in post traumatic neck pain, Roessingh Research and Development, the Netherlands, March 2003, ISBN 90-75452-27-6.
10. Jannink, M. J. A. Usabillity of custom-made orthopaedic shoes in patients with degenerative disorders of the foot, Roessingh Research and Development, the Netherlands, September 2004, ISBN 90-75452-28-4.
11. Blokhorst, M. State-dependent factors and attention in whiplash associated disorder, Roessingh Research and Development, the Netherlands, January 2005, ISBN 90-365-2111-4.
12. Buurke, J. H. Walking after stroke co-ordination patterns & functional recovery, Roessingh Research and Development, the Netherlands, February 2005, ISBN 90-365-2140-8.
13. Salm, A. van der. Spasticity reduction using electrical stimulation in the lower limb of spinal cord injury patients, Roessingh Research and Development, the Netherlands, October 2005, ISBN 90-365-2253-6.

14. Snoek, G. J. Patient preferences for reconstructive interventions of the upper limb in tetreplegia, Roessingh Research and Development, the Netherlands, December 2005, ISBN 90-365-2255-2.
15. Kroon, J. de. Therapeutic electrical stimulation of the upper extremity in stroke, Roessingh Research and Development, the Netherlands, December 2005, ISBN 90-365-2269-2.