Aus dem Institut für klinische Neurowissenschaften und Medizinische Psychologie der Heinrich-Heine-Universität Düsseldorf

Direktor: Univ.-Professor Dr. med. A. Schnitzler

Improving Endurance Training in Neurorehabilitation through Competition

A Proof-of-Concept Study in Stroke Patients

Dissertation

Zur Erlangung des Grades eines Doktors der Zahnmedizin

der Medizinischen Fakultät der Heinrich-Heine-Universität Düsseldorf

Vorgelegt von

Rebecca Handermann

2018

Als Inauguraldissertation gedruckt mit der Genehmigung der medizinischen Fakultät der Heinrich-Heine-Universität Düsseldorf

Gez.:

Dekan/in: Prof. Nikolaj Klöcker

Erstgutachter/in: Prof. Alfons Schnitzler

Zweitgutachter/in: Prof. Andrea Icks (Institut für Versorgungsforschung und Gesundheitsökonomie)

Für meine Eltern

Teile dieser Arbeit wurden veröffentlicht:

Studer, B., Van Dijk, H., Handermann, R., & Knecht, S. (2016). Increasing self-directed training in neurorehabilitation patients through competition. *Progress in Brain Research* (*229*) 367-388.

1. Abstract

1.1 Deutsch

Schlaganfallpatienten unternehmen eine neurologische Rehabilitation in spezialisierten Zentren, um resultierende motorische Defizite [1] auszugleichen. Eine effektive motorische Neurorehabilitation zeichnet sich dabei durch das Ausüben von zahlreichen Wiederholungen und durch deren Intensität aus [2-7]. Es gilt also einen Balanceakt zwischen den Anforderungen an eine erfolgreiche Neurorehabilitation und limitierten zeitlichen, personellen und finanziellen Ressourcen [8-10] zu meistern. Aus diesem Grund wurde eine zusätzliche Therapie, das Eigentraining, eingeführt. Dabei spielt die Motivation des Patienten eine entscheidende Rolle, um das individuelle Rehabilitationspotential voll auszuschöpfen [11]. Unglücklicherweise wird diese Therapie in der Realität des klinischen Alltags aufgrund mangelnder Motivation nicht im gewünschten Ausmaß umgesetzt. Dies hat eine Limitierung des individuellen *Reha-Outcomes* zur Folge [12, 13]. Vorherige Studien, z.B. aus dem psychologischen [14], sportwissenschaftlichen [15] und ökonomischen Bereich [16] haben sich bereits intensiv mit dem Effekt von Wettbewerb auseinandergesetzt. Es hat sich gezeigt, dass Wettbewerb zu einer Leistungssteigerung in einer Vielzahl von Kontexten führt. Ziel dieser Studie war es, diesen Effekt im medizinischen Bereich zu testen. Forschungsfragen beinhalteten im Detail, ob Wettbewerb zu einer Steigerung von Dauer und Intensität von Eigentraining führt und wenn ja wie stark ist dieser Effekt und welchen Mechanismen unterliegt er?

Dazu unternahmen in einer klinisch-experimentellen *proof-of-concept* Studie mit *within-subject design* stationär behandelte Schlaganfallpatienten in einer spezialisierten Einrichtung für Neurorehabilitation, der St. Mauritius Klinik in Meerbusch, ein Eigentraining. Dieses wurde beispielhaft als kardio-respiratorisches Ausdauertraining auf Bewegungstrainern durchgeführt. Das Ausdauertraining fand unter drei experimentellen Bedingungen statt, bestehend aus zwei Kontrollbedingungen und einer Interventionsbedingung, „*competition*“. Die Reihenfolge der Bedingungen wurde zuvor pseudo-randomisiert. Die Trainingsergebnisse waren das Primärergebnis und wurden für jeden Patienten und jede experimentelle Bedingung aufgezeichnet und miteinander verglichen. Dabei wurden unter der Bedingung Wettbewerb die höheren Trainingsleistungen erwartet. Zusätzlich fanden Leistungstests statt, die die Teilnahme an der Studie ummantelten, um eine objektive Bewertung der Veränderung der Leistungsfähigkeit innerhalb der Studie zu gewährleisten. Als Sekundärergebnisse dienten die subjektive Anstrengungsempfindung des Eigentrainings unter Zuhilfenahme der Borg-Skala [17] und die Messung der Herzfrequenz während des Eigentrainings. Beide Variablen wurden auf ihr Verhalten in Bezug auf den zeitlichen Verlauf und auf das Vorhandensein von zusätzlichen Nebeneffekten ohne spezifische Vorhersagen getestet.

Die Ergebnisse zeigten, dass die Trainingsleistung signifikant unter der experimentellen Bedingung *competition*, nicht aber unter Einfluss der beiden Kontrollbedingungen, anstieg. Probanden trainierten unter Einfluss der Bedingung *competition* länger und intensiver. Die Auswertung der Leistungstests konnte bestätigen, dass die Mehrheit der Studienteilnehmer eine Verbesserung der kardio-respiratorischen Fitness erreichte. Die Sekundärergebnisse zeigten, dass weder das Anstrengungsempfinden noch die Herzfrequenz einer Adaptation über die Zeit hinweg unterlagen. Auch konnte kein Einfluss der Trainingsleistung über den Effekt von *competition* hinaus durch Nebeneffekte wie z.B. Nervosität oder Angst festgestellt werden. Es wird angenommen, dass der leistungssteigernde Effekt von Wettbewerb durch eine gesteigerte extrinsische Motivation entstanden ist. Das Eigentraining könnte dabei um den Faktor „Gewinnen“ aufgewertet worden sein [18-20]. Das Auftreten leistungshemmender Effekte wie Angst, wird aufgrund der vollen experimentellen Kontrolle und der mehrheitlich gesteigerten Trainingsleistung als unwahrscheinlich betrachtet.

Diese Studie stellte einen ersten Ansatz zur Testung von Wettbewerb mit Patienten in der Neurorehabilitation dar. Es lässt sich zusammenfassend festhalten, dass *competition* ein wirkungsvolles Instrument zu Steigerung von Eigentraining ist. Dadurch könnte die geforderte Steigerung der physischen Erholung von Schlaganfall Patienten in der Neurorehabilitation in Bezug auf Mobilität, Ausdauer und Gesundheit erreicht werden.

1.2 English

Stroke survivors cope with consequential handicaps [1] while undertaking a neurorehabilitation in specialized stroke facilities. An additional rehabilitation measure, self-directed training, was added to neurorehabilitation schedules to manage the balancing act between requirements of a successful neurorehabilitation, and limited time, financial and human resources [8-10] and the importance of frequency and intensity of physical exercises for the motoric rehabilitation outcome [2-7]. Thereby, motivation plays a pivotal role in utilizing a patient’s individual potential of physical recovery [11]. However, a discrepancy between workout recommendation for self-directed training and the effective number of exercises due to a lack of motivation by patients has been reported [13, 21]. This severely restricts patient’s rehabilitation potential [12]. Previous studies from fields like psychology [14], sports science [15] or economy [16] have examined effects of competition intensively. They found that competition evokes higher performance in diverse contexts. This study set out to examine the effect of competition in the medical field. Study questions incorporated in detail whether competition increases duration and intensity of self-directed training and if so, how strong is this effect and how is this mechanism modulated?

For this purpose, this dissertation was performed as a clinical experimental proof-of-concept study, which follows a within-subject design. The study was conducted at a specialized neurorehabilitation facility at the Mauritius Hospital, Meerbusch. In-patient stroke patients undertook self-directed training exemplary as cardio-respiratory endurance training on wheelchair-compatible bicycle trainers. Exercises were undertaken under three experimental conditions. These consisted of two control conditions and the intervention condition “competition”. Order of condition was pseudo-randomized prior to exercises. Training results, defined as training performance, were collected as a primary outcome and compared for each experimental condition and each participant. Training performance was hypothesized to be highest during the condition competition. An additional performance test framed the participation in the study and served as an assessment tool for the objective modification of performance capability through self-directed training in this study. Moreover, as secondary outcomes, the subjective perceived exertion based on the Borg scale [17] and the increase in heart rate during self-directed training were measured. Both variables were tested in relation to their behavior over time and helped to identify potential side effects without specific predictions.

Results obtained from statistical analysis showed that training performance increased significantly during the intervention condition “competition”. Participants performed self-directed training longer and more intensively in the intervention condition. Performance tests confirmed that most participants improved their cardio-respiratory fitness through self-directed training. Secondary results showed that perceived exertion and increase in heart rate were not influenced by time passed since the beginning of measurements. Also, no manipulation by side effects like nervousness or anxiety were identified beyond the effect of competition on training performance.

The increase in training performance during the interventional condition competition was understood because of increased external motivation by an enhanced benefit of the task through the cofactor “competition” [18-20]. Study design allowed for full experimental control, whereas the appearance of barriers to performance through negative emotions like anxiety or increased pressure is considered unlikely. Also, performance was increased predominantly rather than hampered.

This dissertation serves as a first approach to tests the eligibility of “competition” in un-healthy test persons rather than healthy ones. Considering promising results of the impact of “competition”, this dissertation claims that this element could be a novel tool to increase motivation for self-directed training. This way, the neurorehabilitation outcome of stroke patients could be enhanced in the demanded way by raising neurorehabilitation outcomes in terms of mobility, endurance and general health.

2. List of Abbreviations

ADL	Activities of daily living
AF	Arterial fibrillation
AHA	American Heart Association
ANOVA	Analysis of variance
BAR	Bundesarbeitsgemeinschaft für Rehabilitation
BDI-II	Beck Depression Inventory Two
BP	Blood pressure
Borg RPE	Borg ratio of perceived exertion
BZ	Blutzucker
CHD	Coronary heart disease
COPD	Chronic obstructive pulmonary disease
e.g.	Exempli gratia
EF	Ejektionsfraktion
ESPro	Erlangen Stroke Project
ESI	European Stroke Initiative
EUSI	European Union of Stroke Initiative
CT	Computer tomography
Kcal	Kilo calories
f	female
GEE	Generalized estimating equation
h	Hour
HADS	Hospital Anxiety and Depression Scale
HRmax	Maximum heart rate
HRmaxΔ	Maximum heart rate for training session
HRmean	Average heart rate
HRrest	Heart rate at rest
HRSC	Heart rate safety cut
ID	Identification
IZPH	Interdisciplinary Center for Public Health Studies
kg	Kilogram
min	Minute
mmHg	Millimeter Quecksilbersäule
NYHA IV	New York Heart association classification (for assessment of cardiac insufficiency) stage four
MTK	St. Mauritius Therapieklinik
MRT	Magnetic Resoance Imaging
n	Total number of cases
OCPS	Oxfordshire Community Stroke Project
rpm	Rounds per minute
RKI	Robert-Koch-Institut
RR	Riva-Rocci (blood pressure)
SD	Standard deviation

Sig.	Signifikanz
TVT	Tiefe Venenthrombose
UMNS	Upper Motor Neuron Syndrome
USB	Universal serial bus
vs.	versus
VPN	Virtual private network
W	Watt (international unit)
WCBT	Wheelchair-compatible bicycle trainer
WHO	World Health Organization
ß-Blocker	Beta-blocker medication
%HRmax	Percentage of maximum heart rate

3. Table of Contents

4. Introduction

4.1 Preface

Being the main reason for handicaps [1], the stroke reached second place in the most common causes of death in industrialized countries [22]. The disease is known to be the most expensive discipline in terms of medicine [23]. Likewise, strokes are the neurological disease with the highest incidence [24], causing complex defects in the sensory-motoric, cognitive, social and emotional field. Based on increased knowledge about this disease, a change in healthcare structure occurred with improvements in clinical diagnostic and neurorehabilitation [25]. These improvements led to better prospects for the patients concerned.

Although an incidence of a stroke is declining among groups of people older than 65, strokes become an issue for future generations due to demographical changes [25]. Even though public healthcare has experienced major improvements, risk factors like tobacco consumption, hypertonia or a sedentary lifestyle are still not mastered among the public [26].

Managing the burden of a stroke, patients undergo neurorehabilitation measures where coping with current or permanent handicaps is of prime importance [27]. Only then can patients re-participate in their social environment and activities of daily life (ADL) [27]. However, neurorehabilitation after a stroke does not follow a homogenous concept due to the variety of possible limitations. These depend on the location and dimension of damage on the affected brain territory and the pre-stroke medical history. Therefore, an individual agenda must be developed for each patient [27, 28]. Thereby, the active participation of the stroke survivor is an essential cofactor in neurorehabilitation proceedings [11]. Equally, a rehabilitation process demands a great deal from patients because the relearning of motor function is most efficient if performed at high frequency and intensity [2-7].

However, many brain-injured patients are not able to utilize their individual rehabilitation potential [29, 30]. Reasons for this are argued a lot in current research. Two basic problems have been identified [31]. The first basic issue is that resources for neurorehabilitation measures are finite [31, 32]. There is a global need for a cost-efficient solution, that is saving human, financial and time resources [31]. Hence, a supplementary rehabilitation measure, the self-directed training, is a widely-inserted instrument in stroke facilities. The existing body of research showed that this training led to higher rehabilitation outcomes by increasing the crucial variables intensity and number of repetitions [e.g. 12]. This therapy is performed unsupervised and in addition to regular rehabilitation schedules. Self-directed training can be performed in multiple ways for example as functional training or as cardio-respiratory endurance training to increase the stamina and strength of participants. One example is the use of motor-assisted cycling tools for this purpose.

However, considering that this additional therapy does not provide any supervision or control by a therapist, this approach meets its limits. This leads to the second basic issue, which is a result of reduced drive [31]. Even though a broad acceptance towards this therapy among in-patient stroke survivors in neurorehabilitation care does exist, the expenditure of time spent and the total number of exercises is below recommendations [13]. Some argue that the basic issue with the insufficient realization is of motivational nature [21]. It is hardly surprising that this unsupervised form of training without the crucial re-encouragement of therapists is usually not undertaken as intended [13] (when considering, for example, finding motivation yourself to do sports after a long working day rather than relaxing). Beyond that, it has been found that mental stamina and the frustration threshold is reduced in stroke patients [33]. This is due to multiple impairments that make exercises even more difficult [33]. Therefore, self-directed training can be understood as a prime model of the loss of motivation in neurorehabilitation.

Considering that the intensity and number of repetitions of exercises in neurorehabilitation are pivotal for the neurorehabilitation outcome [2, 3, 5-7] and the burden to manage limited resources [32], the need for increasing motivation for self-directed training becomes apparent. An interesting question thus arises on how to enable stroke survivors to overcome their motivational barriers to exploit their full neurorehabilitation potential. Previous scientific approaches examined the factor competition. Overlapping results were found in fields like sports science [15], economy [16] or in research from psychology using experimental tasks [14]. They found that the introduction of competition augmented performance and increased the effort of test persons in diverse contexts. Thus, this study project intended to transfer this knowledge to the field of medicine. It was intended to measure the effects of competition on the representative example of stroke patients performing self-directed training as cardio-respiratory endurance training in neurorehabilitation by using motor assisted-cycling tools.

4.2 The cerebrovascular Insult

4.2.1 Definition of a Stroke

The cerebrovascular insult is a collective term for non-traumatic events causing the cell death of brain tissue due to a vascular disorder commonly associated with increased risk factors. Stroke is occasionally the result of a blockade or a rupture of a brain-feeding vessel. Thus, energy supply is disturbed, which causes serious damage that varies strongly from case to case and may even result in sudden death. Thereafter, depending on the affected brain section, victims cope with complex deficits and handicaps.

4.2.2 Epidemiology of a Stroke

The stroke, the neurological disease still high-incident world-wide [1, 24], is also most frequently responsible for handicaps in industrialized countries [1, 23]. Considering that the cerebrovascular insult is reported to take second place in the most common causes of death [22], dealing with the intensive study of this complex clinical picture and its consequences for victims is crucial.

Seen around the world, a total of 16 million people experience a cerebrovascular insult as an initial event [34]. However, a characteristic of this disorder is the major need for secondary prevention. In the United States, for example, 795 000 people suffer a stroke annually, from which 85 000 suffer from a recurrent insult [26]. Fortunately, according to the health report of the German Robert-Koch-Institute (RKI), a positive development among first-time strokes and of mortality is noticeable [25, 33, 35]. The RKI explains this development as increasing scientific knowledge and general improvements in healthcare and health awareness [25, 33, 35]. A stroke is a disorder of seniority with the average age of suffering a stroke being 65 [36, 37]. Here, numbers show a downtrend in incidence in this age group [26]. Interestingly, the total number of first-time events of a stroke is even rising [38]. Due to demographical changes, the population that is older than 60 years is growing, which makes further improvements in the neurorehabilitation of a stroke a topical issue [38-43].

Worldwide, cerebrovascular accidents are responsible for 9.7% of all deaths [34]. The American Heart Association (AHA) observed that death rates due to a stroke in the United States equate to one death every four minutes [26]. In Germany, within the first year, one third of the first-time stroke patients died [44, 45]. The second third is a long-term nursing case [46]. The last third of stroke survivors deal with aftereffects ranging from mild limitations of independency to severe restrictions in function [47, 48]. About 42% of stroke patients performed a neurorehabilitation in 2011 [49]. The high number of incidences and the complex and sometimes also permanent disabilities following a stroke lead to remarkable medical treatment requirements. This causes major social and economic costs [23, 43]. An incidence-based, bottom-up study from 2006 by Kolominsky-Rabas [45] demonstrated treatment costs based on a model community for Germany (*ESPro*). In 2004, a total of 7.1 billion Euro treatment costs for first-time ischemic stroke cases were estimated for Germany [45]. Regarding costs of a single newly diagnosed stroke survivor, mean rehabilitation costs are the most expensive share of 37% in first-year follow-up costs [45]. After 4 years, further out-patient treatments raised this proportion to 49% of the total expenditure [45]. Given that this study only considered first-time ischemic strokes, the effective financial burden may be even higher than the report indicated. Pointing out the importance of stroke care beyond social and economic aspects [45], the status in neurorehabilitation is still in need of further improvements.

4.2.3 Etiology and Pathophysiology of cerebrovascular Diseases

The concept of a stroke refers to the pathophysiological event of focal energy supply interruption of the brain tissue, caused by a vascular disorder which leads to neurological deficits. Functional metabolism of brain tissue has little tolerance, and after 8-10 minutes an irreparable destruction of brain tissue proceeds [50]. Depending on the affected brain territory, neurological symptoms and deficits beyond repair evolve. A cerebrovascular event is a collective term which describes malfunction of vascular supply of multiple etiologies and symptomatology, but can broadly be distinguished as ischemic disturbances and bleedings, as demonstrated in the following and in Fig. 1.

4.2.3.1 The Ischemic Stroke

In general, there are two types of cerebrovascular insults. The ischemic insult causes about 87% of all cerebrovascular events [26] (see Fig. 1). It is characterized by a disturbance of the brain circulation and thus energy supply with glucose and oxygen due to local closure of vascular vessels [51]. Many ischemic insults result from an underlying arteriosclerosis. They are characterized by plaque deposition on vascular walls, causing a restriction of lumen (stenosis), for instance at the carotid bifurcation. Vascular occlusion of brain-supplying arteries can be caused by a detached thrombus or plaque particles.

4.2.3.2 The Hemorrhage Stroke

The cerebral hemorrhage is the result of a massive bleed on the brain. Two main sub-groups of intracranial bleeds can be distinguished (see Fig. 1): (i) the intracerebral bleed, accounting for 10% of strokes, [26] and (ii) the subarachnoid bleed, which is responsible for 4% of stroke events [52]. Cerebral hemorrhage can develop based on pre-existing high blood pressure (hypertonia), an amyloid angiopathy or a pathological vessel malformation. As a result of long-term high blood pressure, an alteration of vessel wall occurs which leads to a rupture on predilection sites, the arterioles (rhexis bleeding). The amyloid angiopathy also causes pathological wall malformations due to amyloid plaque deposition. Bleeds by abnormal blood vessels can be caused by an aneurysm, or an arteriovenous or cavernous angioma. The risk of an aneurysm is not just its existence but the probability of a rupture. A rupture of arteries of the base of the scull accounts for 80-85% of subarachnoid bleeds [53].

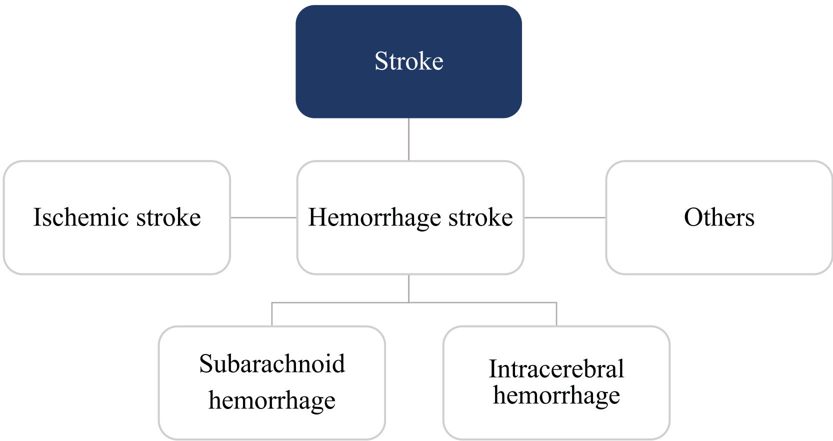


Fig. 1: **Classification of a Stroke**; Figure 1 contains the basic classification of a stroke; the figure is modified from [54].

4.2.4 Risk Factors and Comorbidity

According to World Health Organization (WHO) reports, several risk factors for a stroke were identified [26]. One major risk factor is high blood pressure (hypertonia). Ideal blood pressure is 120 systolic to 80 diastolic. Yet, 77 % of all first-time stroke survivors showed blood pressure (BP) of >140/90 mmHg [26]. Therapies with antihypertensive medication showed a significant reduction of the risk of a cerebrovascular disease (an average of 41%) [26]. Another determinant of a stroke is diabetes mellitus, with an even higher risk among 65-year-olds [26].

Equally important is the risk factor disorder of heart rhythm as well as high blood cholesterol, obesity and physical inactivity [26]. Smoking increases the risk of suffering a stroke from 2 to 4 times compared to a non-smoker [26]. Other influencing factors are nutrition, chronic kidney diseases and sleep apnea [26].

4.2.5 Symptoms and Impairments post-stroke

In general, the severity of symptoms after a stroke depend on the affected brain section and differ only little between types of stroke. Referring to the WHO's classification of functioning, disability, and health, effects on health status like a stroke can be systematized [55]. Disabilities following a stroke are manifested in a generally reduced ability for activities of daily life (ADL) like personal hygiene or mobility [55]. The term "impairment" has been used to refer to pathophysiological conditions of function [55]. In the field of strokes, impairments can result in the form of a hemiplegia, aphasia or spasticity [55].

Post-stroke disorders may consist of motoric and neuropsychological aspects. Motor impairment hemiparesis or hemiplegia is a paralysis of the upper or lower extremities of one half of the body (-paresis) or both (-plegia) [56]. The upper moto neuron syndrome (UMNS), as hemiparesis is also called, has an incidence of about 80% in stroke patients [57]. These can be manifested by an increased and exaggerated muscle tonus (resulting, for instance, in spasticity) or on the contrary, a decreased one (-paresis), which is shown in a weakness of the respective extremity. Likewise, voluntary movements cause an increased energy expenditure because more strength is needed due to muscle resistance against the movement or due to the multiple activation of synergetic muscles (exaggeration) [58, 59].

In the field of neuropsychological deficits, aphasia is a deficit of the faculty of speech, which cannot be traced back to the motoric execution (dysarthroponia). Different types of aphasia can be distinguished based on different leading symptoms. Other neuropsychological deficits incorporate the inhibition of drive, attention deficit and lastly, post-stroke depression, whereof approximately 30% of stroke survivors are affected [60]. Patients suffering from post-stroke depression are limited in the long-term functional outcome compared to others who sustained similar damage after a stroke [61].

Primary syndromes like a hemiplegia on one the hand may on the other result in secondary complications like a diminished endurance level. These also depend on pre-existing comorbidities like suffering from cardiac diseases [62]. Moreover, hemiplegic patients may experience pathophysiological modification in tissues [62]. For instance, muscle shortening is an additional impairment following an UMNS complicating the relearning of motor function and reducing activity [62]. Inactivity in return may lead to further problems like an atrophy of muscles, thrombus formation or the occurrence of bedsores (decubitus) [63]. These variables, including primary and secondary complications, as well as the pre-existing medical history, lead to the very heterogeneous clinical picture following a stroke.

4.3 Neurorehabilitation of Stroke

4.3.1 Neurorehabilitation

In medical acute care, the stabilization of the vital parameters and vegetative status, the limitation of damage, the diagnostics of causes, as well as the secondary prevention are the pivotal agenda [64]. Surveys have shown that the treatment of strokes in specialized centers - stroke units - reduce death rates and achieve a lower permanent functional restriction [65]. Afterwards, 25% of the patients are transferred to a stationary neurorehabilitation [66]. Here, the regaining of function, the identification of deficits and the development of coping strategies are the major objectives [27]. Referring to the recommendations of the European stroke initiative (ESI), the aim is to support stroke survivors to achieve the greatest possible self-sufficiency and the lowest possible care dependency [27]. Patients receive rehabilitation measures phase-specifically, which was established by the federal association of rehabilitation in 1999 [67]. It is possible to draw from a large assortment of applications for each phase by a multidisciplinary team depending on a patient's individual needs. These teams consist, similarly to acute phase therapy, of physicians, nurses and therapists specialized in physic-, ergo- and speech therapy. Passing through these phases, therapeutic care is reduced while demands of rehabilitation measures increase.

Traditional treating methods have been developed over the last century. The Bobath concept from 1976 [68] is still the basis of neurorehabilitation care. The concept is based on the ability to develop new synaptic connections by supporting physiological movements and inhibiting pathophysiological ones. Using this manual technique, physiotherapists impact proprioceptive trigger points on the patient's body to influence physiological movements positively (called "fasciation") and to inhibit pathophysiological acts.

Increasing attention is currently given to the task-oriented concept, which can be resigned to evidence-based strategies. This therapy approach differs from traditional strategies as it follows the current and dynamic scientific evidence. It has been proven, for example, that the number of repetitions of exercises is paramount to functional recovery [2-7]. The more intensive an exercise and the more often patients perform exercises, the higher the rehabilitation outcome [2-7]. A significant difference to traditional strategies is that patients are not treated hand-operated by the physiotherapist. Patients are confronted with real tasks which demand an active involvement *("hands-off"* concept) [27]. Another essential element of modern neurorehabilitation is the "task-specific" content. Neurorehabilitation measurements need to be reasonable for the stroke patients to improve the rehabilitation outcome. This is suggested by several lines of scientific evidence in animal experiments [e.g. 69, 70, 71]. Thus, therapeutic measurements involve the training of activities of daily living (ADL) like getting dressed or activities of housekeeping. Activities are performed step-wise, led by ergo-therapists. Other therapies deal with cognitive deficits, for example speech therapies. Music therapy is used in early neurorehabilitation with multiple indications e.g. reduced consciousness, depression or reduced drive. Another important part of neurorehabilitation is the therapy of sensorimotor function. Sensorimotor training can be conducted by repetitive exercises of everyday gestures like climbing stairs or by use of automated motor supported tools for gait exercises [72]. Lastly, therapies consist of exercise training, which is examined in greater detail in the following chapter.

4.3.2 Exercise Training in Neurorehabilitation

The American Heart Association (AHA) determines three key rehabilitation goals: firstly, the avoidance of complications due to inactivity, secondly the prevention of cardiac and recurrent stroke events, and thirdly the enhancement of cardio-respiratory fitness [63]. Therapies in neurorehabilitation demand a great deal of strength and stamina from patients [73-75]. Due to low exercise tolerance, patients are commonly overstrained by therapy requirements. The effort required is even higher for stroke survivors than for those who are healthy [e.g. 58, 59, 76]. Thus, training therapy in neurorehabilitation is intended to create greater exercise tolerance, improve the functional outcome and reduce the risk of recurrent stroke and cardiac diseases [63, 77].

Training therapy in neurorehabilitation consists of both aerobic endurance training and strength training. Being based on knowledge of sports medicine [78], aerobic endurance training can be defined as an exercise on an intensity that leads to higher stamina [63]. Adaption processes are only achieved by reaching so-called therapy-effective training intensity [79]. This training intensity leads to a stimulus threshold transgression, resulting in remodeling processes of tissue as an adjustment mechanism [63]. Guidelines of the AHA suggest training at an intensity of 50-80% of the maximum heart rate [63]. Therapy-effective intensity and adequate duration of recovery phase can be determined by monitoring the heart rate. The heart rate is known to develop in linear relation to oxygen uptake during an increase of intensity during exercises [79]. In the practical course of neurorehabilitation, the Karvonen formula can be used for this purpose [72, 73, 79]. However, the therapy-effective level of stress does not only correspond with heart rate but also with advanced age as it decreases in older people [79]. To guarantee health-related security while exercising (concerning e.g. the risk of cardiac events), it is recommended that stroke patients undergo graded exercise testing in combination with a broad physical examination beforehand [63]. Through this pre-testing, an evaluation of fitness status is possible. However, more importantly, an identification of individual physical barriers of trainability and thus the well-being of the patient is ensured [63].

Endurance training in neurorehabilitation provides two basic kinds of training methods, (i) the duration method and (ii) the interval method [79]. An adequate time of training leads to an increase in blood circulation, which supports healing processes and training tolerance by developing a more powerful cardio-respiratory system. Moreover, an adaption on a neuronal level in the sense of better communication of the motor unit occurs. As the therapy-effective duration is too strenuous for many stroke patients, interval method often is the more appropriate training method. Here, intensity can be adapted individually e.g. by adapting the parameters of a motor-assisted bicycle trainer. Respecting remodeling processes, training intensity is raised progressively while respecting adequate time for resting. As soon as a certain intensity of exercise is not challenging anymore, intensity is raised because only then is motor learning stimulated [80].

Strength training is supposed to achieve an increase in strength, a prevention of atrophy of muscles and to have a positive influence on the functionally correct use of muscles [79]. Improvements are not only made by the effective increase in muscle size but also by an adaption of neuronal control systems. The basis of sensorimotor abilities like gait is an adequate strength of contraction [72]. The strength may be trained by use of weight, circuit training or isometric exercises [63]. Endurance may be trained by undergoing gait training, simple walking [81] or even jogging if possible. Exercises may also be conducted with partial body weight e.g. by aqua-jogging or by doing the exercise on a treadmill or a bicycle trainer [79]. The latter will be introduced in more detail in the following chapter.

4.3.3 Motor-assisted Cycling Tools applied in Neurorehabilitation

There are many tools for exercising during in-patient neurorehabilitation stay. Which instrument is used for this purpose depends on the patient's individual abilities. Coming from a domestic use, the range of application not only includes outpatient sport- and physiotherapy but also the neurorehabilitation care. Due to many advantages, treadmill training has been proven to be a beneficial tool for aerobic exercise by many studies [e.g. 82, 83-87]. However, different variants of lower-limb cycling tools are becoming more relevant among specialized hospitals and stroke units. Conventional lower limb cycling tools demand a certain level of condition concerning body posture and lower limb function. Also, vertigo and impaired trunk balance would be a contraindication for exercising on this training tool with respect to the risk of falling. Therefore, these training tools are only suitable for advanced patients at a proceeded point of neurorehabilitation.

Patients that suffer from impairment of the lower limb or trunk balance are recommended to use a wheelchair-compatible bicycle trainer. These trainers provide motor assistance which enables users to exercise even with minimum power. Muscle relaxation and an activation of joints can be achieved by using this function in early rehabilitation stages. Due to the motor support, exercising with one paralyzed or even amputated leg is possible and even pedal rotation is achieved at any time. A monitoring of the heart rate is possible and the resistance of pedaling is gradable or degradable in intensity, measured in watts. This function is essential when remembering methods in sports therapy where a certain level of intensity needs to be adjusted to reach therapy-effective training intensity (see chapter 4.3.2).

Considering further that setting goals in stages in the neurorehabilitation process is a basic instrument, the feedback function of both cycling tools is a useful feature. Results of an exercise are presented after a training session, so the training progress is easily assessable. In contrary to the also reliable treadmill exercise, constant monitoring by a physiotherapist (due to the risk of falling and the need to control movements) is not necessary with the bicycle trainer. Thus, patients can impact and evaluate their neurorehabilitation outcome actively. This reflects the credo of the "hands-off concept" of modern neurorehabilitation strategies.

Literature on motor-assisted cycling tools has highlighted many positive impacts on the rehabilitation outcomes. Exercising on a wheelchair-compatible bicycle tool over a period of three months in a domestic surrounding had a positive influence on walking abilities [88]. Another case study examined the endurance training on cycling tools among post-polio syndrome patients. The study confirmed that endurance training on these tools leads to a higher pulmonary capacity [89]. Exercise tolerance (including physical fitness and motor function) as well as the sense of self-worth in stroke patients were improved in a study using cycle ergometers during a period of 12 weeks [90].

4.3.4 Self-directed Training in Neurorehabilitation

Even though there has been great progress in neurorehabilitation in patients with a stroke, it has been shown that there are large differences in the individual rehabilitation outcome of patients [29, 30]. A reason for this is that common institutions for rehabilitation are not able to respond to the demands of research on the intensity [2-6, 91] and amount of training. This is due to logistical and economic reasons [31]. Thus, self-directed training was integrated in neurorehabilitation schedules. This training is an exercise conducted without direct therapeutic supervision. Patients perform an exercise independently and additionally to everyday therapies. Hence, self-directed training serves as a cost-, time- and personnel saving solution for institutions [31]. Moreover, the therapy considers principles of evidence-based strategy in neurorehabilitation (4.3.1). Patients can impact their rehabilitation outcome actively by exercising additionally to regular rehabilitation schedules. Thereby, self-directed training can be performed in multiple ways as a functional exercise or as endurance training. Also, use of training tools like bicycle trainers can be considered for this purpose. Due to beneficial effects of self-directed training on neurorehabilitation outcome, it is a widely-inserted tool in neurorehabilitation. In a multi-site randomized controlled trial, self-directed training of upper limb function was examined in in-patient stroke participants [12]. Participants that underwent self-directed training in addition to rehabilitation therapies for 4 weeks showed significant improvements in upper limb function compared to the control group who only received regular rehabilitation measures. Thus, self-directed training is assumed to be a valuable solution to achieve greater functional outcomes for stroke patients in neurorehabilitation. Despite the scientific success, the major disadvantage of this approach is that self-directed training is carried out far less than necessary [13]. Although patients were generally interested in this task, a lack of motivation was reported as a reason for this behavior [21]. This circumstance may result from the challenging process of a neurorehabilitation, which demands a great deal of stamina and strength from patients [33]. Also, a lack of motivation can simply be the result of a stroke, as mentioned in 4.2.5. Motivating patients through more comprehensive face-to-face care by therapists could be an option. It is known that social support by therapists and other patients plays a significant role in enduring the rehabilitation process [92]. However, again limited resources in stroke care are being faced [31]. Neurorehabilitation measures can often not provide the required amount of time and intensity of training due to economic limitations and staff shortages [8-10]. Enhancing therapist–guided exercises could only go hand in hand with extensive expenditure which cannot be provided by common institutions (see 4.2.2).

4.4 Motivation and Competition in Light of Psychology

Considering that motivation is an essential cofactor of the neurorehabilitation outcome, motives and possible incentives of individuals need to be understood to find novel approaches to increase the success in stroke recovery. The following chapter intends to give a definition of motivation and deals with the origins and effects of motives as defined by multiple disciplines based on the current standard of scientific knowledge.

4.4.1 Development and Impact of Motivation

Motivation can generally be defined as a stimulus to take an action emerging in multiple ways and from diverse contexts [93]. The existing literature on motivation originates from many disciplines and to date, no unified consensus on a single definition has been applied [94]. The large volume of published studies can be summarized as emerging from the field of biology, psychology and economics [93]. Also here, due to the different objectives of the disciplines, research occurred independently, although findings, to some extent, coincide [93].

Motivation is commonly referred to as a directed behavior pursuing a certain objective which drives the ambition for and the enduring of a mental or physical action [95]. Transferring this theory to everyday life, motivation can be understood as an attempt to explain an individual's action [93].

Basically, motives can be divided into congenital and acquired origins [96, 97]. On the one hand, pursuing life-sustaining goals, like satisfying hunger, are defined as congenital motives [98]. Congenital forces can therefore be understood as an intent to meet elemental biological demands [93]. Acquired goals, on the other hand, deal with motives that emerged throughout a lifetime, like the urgency to make a living [99]. These goals are shaped individually depending, for instance, on a person's social or cultural environment, and may target congenital goals indirectly e.g. the goal to receive salary to pay for food [93, 100, 101].

In contrast, research from the field of economy suggests that the incentive of goal-directed behavior originates from external motives, which in this discipline is mostly represented by financial rewards [93, 102-104]. The central thesis of economics states that behavior is mainly driven by the expectation of a benefit. Only if a task is deemed profitable compared to its necessary costs, is performance triggered. The benefit, the perceived probability of mastering a task and the social recognition gained through the relative activity are believed to be subject of individual considerations [105].

In the field of psychology, Deci postulated in 1971 that human behavior can be further distinguished into an intrinsic and extrinsic origin of motivation [106]. It can be said that intrinsic motivation arises by reasons of the activity itself for instance by the simple enjoyment of a performance [106]. This inner interest drives an action based on a human’s individual emotional participation, without the expectation of any profits. Extrinsic motivation, in contrast, represents an incentive externally driven by the expectation of some kind of reward [106], depending on personal conviction and the individual character [107].

Thus far, countless theories as to the concept of motivation have been published [108]. However, each theory only concentrates on partial aspects of the dynamic and multifactorial mechanisms of human motivation [109]. Self-determination theory, for example, was introduced by Deci and Ryan and focuses on intrinsic needs [110]. This theory is based on the assumption of three modulators for intrinsic drive: i) feeling competent, ii) feeling related and iii) feeling autonomously [110]. The first modulator describes the origin of motives as a need to demonstrate one’s competence of performing an action. The second one, serving as a social aspect to motives, represents the need to receive social support from others. Thirdly, autonomy describes the need to feel self-dependent to achieve a desired outcome or to avoid a certain outcome. However, the theory is not sufficient to fully explain origins of motivation, but may help to distinguish between various characters who are driven by different shares of the three variables [93]. Reviewing literature on novel ways to increase motivation, Deci and Ryan defined three rules [111]. Firstly, they assume that increased motivation results if a person feels self-determined during an activity [111, 112]. They postulated in 2000 that:

“*When people’s goal-directed behavior is autonomous rather than controlled, the correlates and consequences are more positive in terms of the quality of their behavior as well as their health and well-being*”, Deci and Ryan, 2000, page 243.

Secondly, the activity or task must be adequate for the person concerned, meaning that the level of demand must match the person’s individual capability [111, 113]. Thirdly, positive feedback in comparison to negative increases the motivation for this task [111]. This is because of the need to feel competent, which represents a theoretical reward [106, 111, 112, 114].

Considering diverse theories on the origin and the effects of competition, a more precise model, compared to the self-determination theory, was created. The benefit-cost framework is an approach taken in order to find practical ways to enhance motivation for a concrete task rather than a scientific explanation approach on the development of motivation [107]. This model assumes, like economic theories, that before taking an action, expected associated costs and benefits of the relative task will be evaluated by an individual. Working adversary, the one variable that prevails will drive the direction of motivation. However, in contrast to economics, the benefits of a task can be both intrinsic or extrinsic sports [107]. A sports game can be considered as an example. Here, intrinsic motivation could be enjoyment of the sports game itself. The extrinsic motive could be the expectation of winning a medal by outperforming others. Costs also consist of extrinsic and intrinsic motives. Here, intrinsic motives include e.g. the feeling of indisposition during the exercise itself. Extrinsically set goals could incorporate undesired outcomes like a social descent or the time exposure for the activity which could have been spent on another optional activity [115, 116]. This model assumes further that benefits and costs result from a i) multifactorial consideration, that ii) motives are not objective and that the framework is iii) state-dependent [107]. Firstly, the multifactorial consideration includes intrinsic and extrinsic factors from diverse theories on the root of motivation and its consequences. It is believed that these are being summarized depending on individually different weightings by a person. However, the benefit-cost framework does not provide a forecast on how this summarization of the total benefits and costs of a certain tasks is performed in single cases. Secondly, motives are subject to individual human characteristics. More ambitious behavior, for instance, was found in individuals that experienced challenges with opponents in their past [117]. In the context of this study, expected costs of a physical activity will be greater for a stroke patient with a strongly reduced general health condition than for a healthy person [107]. Thirdly, the framework of state dependency is variable as are human considerations at a certain time and stage of life [107]. Thus, propositions agree with findings from the field of biology and economics. These also determined a situation-related behavior [101] and variable responsiveness to different motives in individuals [e.g. 118].

Lastly, in the field of molecular biological research on motivation, neuroendocrinological factors were identified to drive human actions. The neurotransmitters dopamine, serotonin and norepinephrine as well as hormones like testosterone, estradiol and oxytocin were identified to influence performance on the neural level [119]. Thereupon, the steroid hormone testosterone plays a crucial role in the process of making a choice while being neuroactive on the dopaminergic system [120, 121].

4.4.2 Competition – A new Strategy?

To find other approaches to increase motivation, factor competition was examined first. Competition is a crucial factor for evolution in the animal and plant kingdom by fighting combatively over nature's resources to survive [122]. However, also in our modern society, competition drives human motivation in disciplines like economy, politics, business, education and sports [123]. It is met in numerous areas of life from the interpersonal level to the regulation of supply and demand in economy [124]. Simple everyday life examples show that competition can be experienced as both positively by e.g. a playful game among friends and negatively by the pressure to perform well in school or at work [124]. In the field of psychology, competition can be defined as a one-to-one rivalry between humans which intends to outperform an opponent [124]. A winner and a loser result from this occasion. According to the aforementioned psychological theories, this is a result of the attempt to show competence [106, 111]. However, similar to research on motivation, a standardized approach on competition or competitiveness is missing [124].

Seen in the discipline of economy, competition is a major force. This was highlighted by trials investigating human behavior in auctions. They examined the change of the subjective value of an item while bidding. They found that people were triggered to expect the value of an item to be higher during auctions than it was perceived originally. As a result, a frequent overbidding of items occurs [125-129].

In the field of cognitive achievements, previous research focused on identifying and evaluating competition upon increasing motivation for academic performance [130-132]. Based on scientific evidence that learning outcomes improve if a person is motivated [133], a moderate tournament was carried out at university [130, 131]. Games were used to increase the intrinsic motivation of students in the learning process. This research confirmed the effectiveness of competition as a gaming element on improving learning outcomes in an academic surrounding.

Investigating competition associated with physical performance, DiMenichi and Tricomi found in 2015 that reaction times increased through competition [134]. Physical competence was raised in sports like basketball [135] and cycling [136]. Outcomes were significantly higher in the competitive environment. As an attempt to isolate the effect of competition, performance outcomes between different assessment tools were examined [124]. Results from this extensive study, consisting of a meta-analysis of 64 trials, showed that inserted training style (laboratory tasks or sport tasks) was not decisive to performance outcomes. Interestingly, results improved significantly during a competition in all cases in comparison to self-directed tasks.

It is known that the origins and effects of motivation are also influenced by neuroendocrinological factors [122]. Hence, competition is represented on the neuronal layer

[122]. A brain section, the striatum, located in the medial prefrontal cortex, is responsible for the evaluation and rewarding system [137-142]. There, it was found that responses (the so-called Bold Signal) were more significant during a competitive context [143, 144]. Several lines of evidence suggest the existence of a “winner effect”, which is characterized by the distribution of testosterone on the neuronal level [e.g. 122, 145, 146]. This neuroactive sex hormone is involved in neurobiological processes, for example during combats which share elements with competition [147]. Interestingly, winning a competition results in a higher testosterone secretion, while losing leads to a lower level of this hormone [148]. In this line, it is also interesting to note that testosterone is expressed by different shares in males and females [149]. Moreover, a correlation between the release of the steroid hormone testosterone and the competitiveness of an individual has been identified [150-152]. Adversely, a sub-function of gonads in men, and therefore a reduced level of testosterone production, is associated with reduced effort [153].

On the basis of theories from biology, Burguillo (2010) claims that competition leads to an increase of cognitive performance due to increased inner motivation through games [130]. He proposed that the competitive gaming situation increased the amusement of the activity itself. In contrast to this assumption, competition can also be assessed as an external reward through the expectation of a reward. This could be a position in sports tables [122]. Another explanation is that winning a competition is a great experience, and seeking this enjoyment, performances were higher [154]. Plus, the subjective value of the activity itself improves due to higher “profit” in the case of winning [18-20], which is in line with propositions of the benefit-cost framework. Another approach to explain the effects of competition was taken by authors that examined auctions. They interpreted increasing motive force during competitive environments by “avoidance goals” [110, 155] . Motivated behavior might be driven by the attempt to try to prevent a loss in social recognition [147, 156] or by trying to prevent the regret after having lost a contest. It is proposed that people regret not having set a higher bet if someone else out-bid them at the auction [157, 158]. An overview of approaches taken to examine competition and proposed reasons for effects of competition is presented in Fig. 2.

Other findings on the regulation of motivation through competition implied that the effect of competition is only positive if a person believes in possible victory. The person must be sure that the outcome of competition is clearly in their hands [124, 159-161]. Moreover, it was shown that the effect of competition is situation-related [107]. Adding a specific and accurate environment [124, 159], competition is assumed to be a useful modulatory instrument to increase motivation for a specific task.

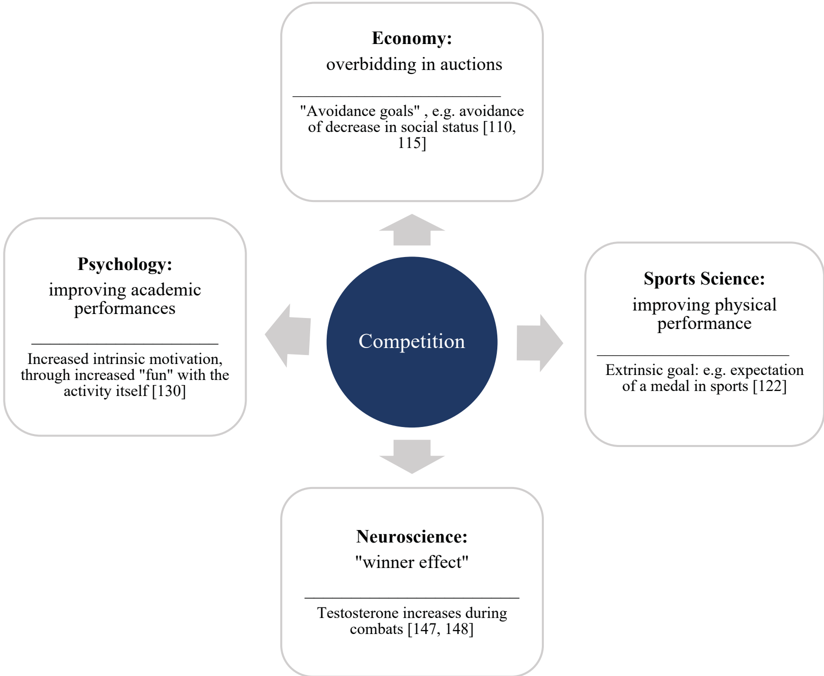


Fig. 2: **Examples of examined impact and effects of competition in a variety of contexts:** the figure presents an overview of approaches taken to examine competition in fields like economy, sport science, neuroscience, psychology and proposed reasons for effects.

4.5 Structure and Target of this Study

Competition has been proven to be a valuable element to increase performance and effort in diverse disciplines and contexts from laboratory tasks [124] to the commercial trade market [16]. However, thus far, competition has hardly been considered for use in the medical field. Self-directed training is a rehabilitation measure most needed to enable patients to exploit their full rehabilitation outcome by increasing the crucial factors intensity and number of repetitions of motor exercises.

The aim of this study is to investigate whether the introduction of competition can increase self-directed training. Moreover, the study question incorporated the question of how strong this effect would be and which mechanism is underlying.

Thus, this study examined in clinical-experimental, proof-of-concept study the use of factor competition on self-directed training. Self-directed training was performed in an exemplary way through cardio-respiratory endurance training on motor-assisted cycling tools by participants undergoing in-patient neurorehabilitation care after suffering a stroke. Training performance was recorded from test persons that underwent three experimental conditions, two control conditions and one interventional condition, called competition. Using a cross-over design with a pseudo-randomized order of condition, each participant passed each condition repeatedly. In the first control condition baseline, the participant received no feedback about their performance. In the second control condition feedback, results of training sessions were reported back to them. In the competition condition, participants were informed to compete against an anonymous (fictive) opponent.

It was hypothesized that training performance will be highest during the interventional condition competition. Additionally, secondary outcomes, the subjective perceived exertion and the heart rate were measured to examine their behavior during training performance without specific predictions. Lastly, performance tests were conducted and served as an objective evaluation measure of change in fitness status.

5. Material and Methods

5.1 Study Design and Setting

This proof-of-concept study used a cross-over controlled within-subject design with three repeated experimental conditions, defined as baseline, feedback and competition. In all conditions, participants undertook self-directed training. Each participant passed each condition multiple times. Intensity and duration of self-directed training were recorded by training tools. Variables constituted the training performance, which served as a primary measure and was compared intra-individually between the three experimental conditions. This proof-of-concept study was conducted at the Mauritius hospital Meerbusch, which is in collaboration with the institute of Clinical Neuroscience at the Heinrich-Heine University in Düsseldorf over a period of 13 months. The rehab hospital, which supplies the greater area of Düsseldorf, is specialized in neurorehabilitation. Test persons were in-patient stroke patients. Measurements of activity collected in this study only took place at the weekends, however, some participants (26.4%) also participated in a related study, with an identical design and setting, conducted during the week [see 31].

5.1.1 Ethic Approval and Consent

A positive ethic vote has been given by the Independent Ethics Commission of the medical faculty of the Heinrich Heine University Düsseldorf, Germany (protocol number 4835). Prior to participation, patients were informed about the duration of the study proceedings, and they gave their written consent (see annex VII). The research project was operated in accordance with the current declaration of Helsinki.

5.1.2 Training Tools

The training tool used in the present study was a wheelchair-compatible bicycle trainer (referred to as WCBT in the following by *THERA-Vital; Medica Medizintechnik GmbH, Germany*). The training tool is also applied in clinical practices in the Mauritius hospital for rehabilitation measures, like group therapies and for the implementation of prescribed self-directed training (see Fig. 3).

Fig. 3: **Wheelchair-compatible bicycle trainer (WCBT);** Figure two shows a wheelchair compatible bicycle trainer by Thera-Vital Vital (by Medica Medizintechnik GmbH). Similar ones were used in this study; ©Medica Medizintechnik

5.1.3 Participants

Participants that were included in this study were receiving neurorehabilitation therapy in the St. Mauritius hospital in Meerbusch after suffering a stroke. Potential adult participants were recruited for the study. If they met the inclusion criteria (see annex V) and none of the exclusion criteria, they were deemed eligible for participation. Moreover, all participants had to give written consent, and the treating physician at the Mauritius hospital had to confirm the medical eligibility for each of the prospective participants (see annex III). Eligibility criteria were that the patient (i) had experienced an ischemic or hemorrhagic cerebrovascular event in a period of at least 2 to a maximum of 20 weeks prior to participation, (ii) can speak German, (iii) has motoric impairment of the lower extremities which allows training on a wheelchair-compatible bicycle trainer (WCBT), (iv) is able to give written consent and (v) is in a steady medical state. Exclusion criteria included (i) not applicable unsupervised cardiorespiratory fitness training on the inserted training tools due to medical risk factors which could lead to cardiovascular overstressing (E.g. acute myo -or endocarditis, coronary heart disease, cardiac insufficiency (NYHA class IV), acute infection attended by fever), (ii) the existence of a moderate or severe cognitive dysfunction, (iii) suffering from moderate or severe aphasia and (iv) the remaining in-patient stay is expected to be less than 2 weeks. In this case, the remaining time for exercises on the weekends was not adequate to reach the required number of training sessions. For more demographical information on participants of the final sample see Table 1.

In the present study, 637 measurements were recorded from 99 participants using a WCBT. How long a participant performed self-directed training and thus how many training sessions were recorded for each participant depended on the relative treatment period in the Mauritius hospital. A total of 36 participants with 74 measurements had to be excluded from statistical analysis because less than five required training sessions were recorded from them (for reasons see Fig. 4). The most recent cause of data loss was due to missed appointments. Thus, the final sample consisted of a total of 63 participants with a total number of 636 measurements. At least 5 and a maximum of 29 training sessions per person were included in the final statistical analysis.

Analysis of secondary outcome increase in heart rate (%maxHR) included 32 cases (39.3% of the final sample). Cases were selected prior to analysis allowing for the aspect of sufficient measurements of heart rate. The small number of participants that reached an adequate number of at least 5 required recordings of heart rate per session is due to record failures (technical or by human intervention) or because putting on the pulse set was not possible.

30 participants were included in the analysis of performance tests (see 5.2.1). Sample size is due to logistical errors or early discharge of patients.

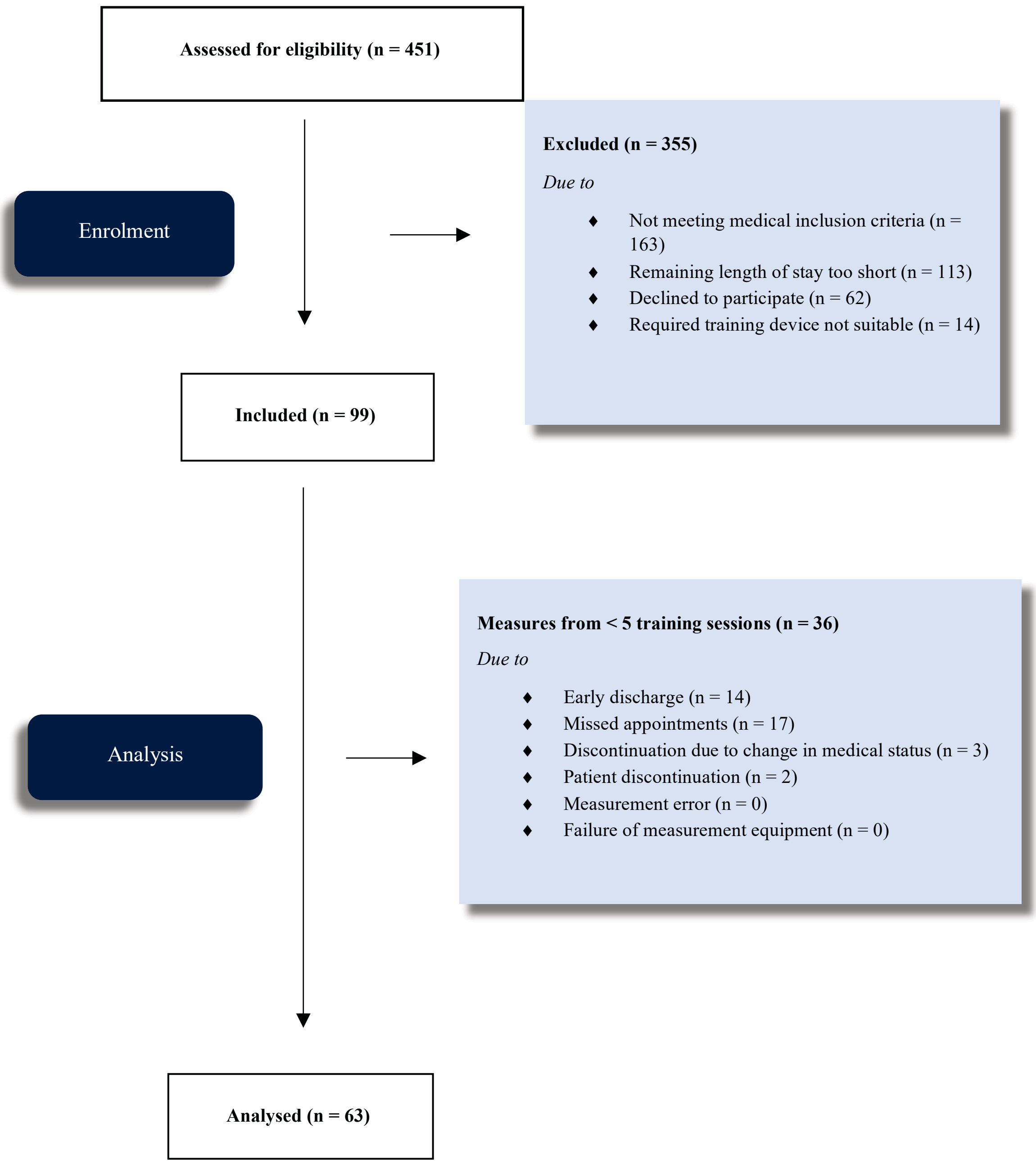


Fig. 4: **Enrolment of this study**: n = total number of cases; figure five gives an overview of the phase of recruiting and analysis from August 2015 to September 2016 at the Mauritius Hospital, Meerbusch. 99 participants participated in the study. The final sample for analysis contained 63 participants. The most recent cause of data loss was due to missed appointments.

Demographical information	**Patient sample**
Sample size	n = 63
Gender *(m/f)*	n = 30/33
Affected hemisphere *(right/left/infratentorial)*	n = 36/25/2
Stroke type *(ischemic/ hemorrhage)*	n = 61/2
Age – *mean/ median (+SD)*	73 /74 (± 8.539)
Recorded training sessions *mean- (+SD)*	20.59 (±12.872)
Diabetes mellitus	19.0 % (n = 12)
Smoking	17.5 % (n = 11)
AF	14.3 % (n = 9)
Alcohol abuse	11.1 % (n = 7)
Kidney disease	9.5 % (n = 6)
COPD	4.8 % (n = 3)
Rheumatism	4.8 % (n = 3)
Liver disease	1.6 % (n = 1)
CHD/Heart attack	1.6 % (n = 1)
Heart Insufficiency	1.6 % (n = 1)
Dementia	0 % (n = 0)

Table 1: **Characteristics of patient sample;** table one presents demographical data for patients included in the study. Most participants suffered from an ischemic stroke (60/2). The incidence of diabetes (19%) was strongest, closely followed by the risk factor smoking with 17.5%; mean = mean value of the data; SD = standard deviation; m = male; f = female, smoking = tobacco consumption, AF = atrial fibrillation, COPD = chronic obstructive pulmonary disease, CHD = coronary heart disease, n = total number of cases; *no data for 5 patients (7.9%)

5.1.4 Consent

Prospective participants were approached in an interview situation. They were informed about self-directed training and the training schedules within the study project. Additionally, written information sheets were given to them (see annex VII). The potential participant had to read and understand all terms and conditions and had to give their written consent to be included. Further, these consent discussions served as a tool to check the suitability in person (for instance the specific manifestation of aphasia).

5.1.5 Severance Criteria

As signed in the consent leaflet, patients could discontinue the study at any time. Moreover, in the event of a sudden worsening of the medical condition, an immediate exclusion of the study occurred.

5.2 Procedure

5.2.1 Performance Test and Training Sessions

Before starting the cardiorespiratory fitness training, graded exercise testing (see annex I) on the WCBT was conducted to evaluate the participant's cardiorespiratory fitness level. Also, the same test was repeated after the last training sessions, prior to the transition from the hospital. Both results were then compared, which served as an assessment tool for the change in fitness level through the participation in the study project. Classifications were defined as (i) "improvement" (ii) "worsening" (iii) "no change" (for details see 5.3.3). The test involves a gradual increase of watt number of the training device. Participants could undergo three steps of intensity (from 26 to 76 W). After 4 minutes the next step was adjusted by increasing the intensity by 25W. Meanwhile the participant's heart rate was monitored, including the heart rate at rest. Termination criteria were (i) subject's pulse was higher than 130 beats per minute (rule-consistent termination) and (ii) participant cancels test (termination by patient). As a secondary outcome, the subjective assessment of exertion was registered subsequently based on the Borg scale [162] by both participant and examiner (self-assessment and external assessment). Moreover, the decrease in heart rate after the test was recorded, but not analyzed. Well-functioning hearts will decrease frequency by at least 12 beats per minute within one minute after the physical exertion period [163]. This measure helped to identify cardiac risk factors prior to exercises and thus the trainability of potential participants in accordance with recommendations of the AHA [63]. The test not only provided an evaluation of the patient's individual fitness level but was also used as an introduction to the training tool prior to the first measurements and to explain the parameters that were about to be recorded during the training sessions.

After performing the test, training sessions started (for an overview on the process see Fig. 5). In the study, participants underwent a self-directed training course on the weekends. They were given two appointments for each day on the weekend with enough time to rest between the sessions. Parameters of training session, meaning the duration (in minutes) and resistance (in kilos ranging from 1-15) were chosen by the patients independently for each training session. Then, self-directed training on the WCPT took place unsupervised. However, a direct pre- and after-training meeting with the examiner framed a training session. In the pre-training meeting the heart rate at rest was measured using an automatic blood pressure monitor (by Omron Healthcare Europe), and positive feedback about the training sessions was given if it was a feedback condition. If previous condition was a competition condition, training results of the participant and results of a fictive opponent were reported. If the prior condition was a baseline condition, no outcome was reported. Depending on the upcoming training sessions, different instructions were then issued (see 5.2.3 for details). In the post–training meeting, the patient was asked to rate the perceived exertion during the training session based on the Borg scale [162].

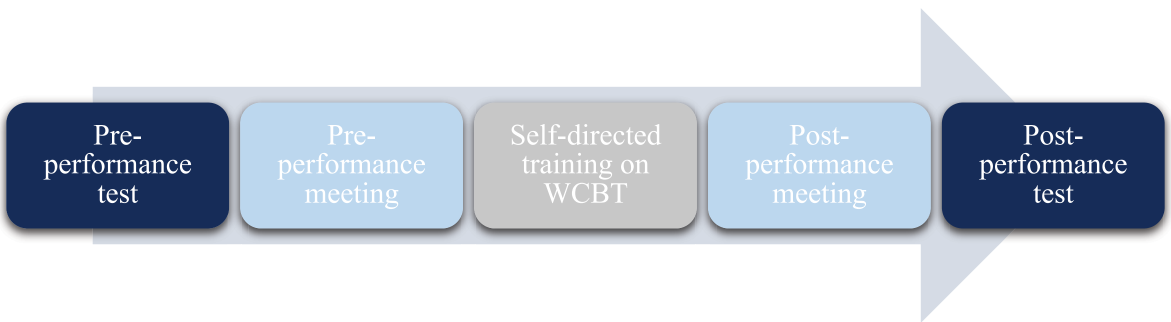


Fig. 5: **Process of Measurement**: WCBT = wheel-chair-compatible bicycle trainer; the figure shows the process of measurements. After the pre-performance test training sessions started, training sessions were framed by a pre- and post-training meeting. Prior to the discharge from the hospital, post-performance test was performed.

5.2.2 Post-trial Interview

Before discharge from the hospital, the participants met the examiner one last time for a post-trial interview. In this meeting, there was room for debriefing. Further, the examiner asked three questions about the subject’s impression of the effect of competition on their training performance: (i) whether the person recognized a motivating effect on having an opponent during a competition term, (ii) whether they had the impression of having trained harder during that same term, and (iii) if they would describe themselves as a competitive person in general. However, this questionnaire was not evaluated in this study.

5.2.3 Conditions

In this study project, three within-subject experimental conditions defined as baseline, feedback and competition were repeated and randomized in their order. The first two conditions served as control conditions, whereby baseline represented the standard control condition and feedback a high-level control condition. Competition served as the intervention condition.

i) Baseline (Control Condition)

The training performance was recorded in this condition, but a cover-up story was used in the pre-training meeting: participants were told that the upcoming training session will not be recorded and not analyzed afterwards due to calibration of the data recording equipment. This condition served as a control condition for basic activity without extrinsic control and equals regular practice of self-directed training. Recordings were covered and no feedback was given in the next pre-training meeting.

ii) Feedback (the high-Level Control Condition)

Contrary to baseline condition, participants were aware that their training performance was being recorded and analyzed. In the pre-training meeting, they were informed that the training session will be recorded, analyzed and that results would be reported back to them before the next training session. This condition was the high-level control condition assessing training activity with feedback and open recording.

iii) Competition (Intervention Condition)

In this term, training activity under the influence of competition was examined. Again, a cover-up story was used that created a fictive antagonist. Participants were told that an anonymous but well-matched opponent was chosen for them, that they would compete against each other and that there would be a winner. The opponent was described as a gender and age-matched patient, who had also suffered a stroke with similar impairments and is approximately at the same level of fitness. However, the antagonist would not perform at the same time, but training results would be compared on the computer before the follow-up training session. In addition, instructions on how to outperform the antagonists were given (e.g. the longer the training session the better, and the higher the intensity the better). They were advised that they will receive results, both their own and the opponent's. In the next pre-training meeting, the participant's training results, and the results of the fictive opponent were reported, as announced before. The participant was then told he had won the competition by a short lead. However, there was one exceptional situation if the participant performed in this study for a long period and training results during competition were notably lower compared to previous sessions. In this case, the participant was told to have lost the competition to retain the credibility of the cover-up story.

5.2.4 Randomization of Order of Experimental Conditions

A pseudo-randomized order of conditions was assigned to each patient in the study to exclude time sequence effects. Randomization of order was performed beforehand by computer generation. Assignment was random and followed the order of recruiting. A sequence was formed in blocks and had to contain all 3 conditions repeatedly and equally numbered. After six training sessions, all conditions had to have been repeated twice (e.g. A, B, C, B, A, C). Yet, orders were not fixed in their length. The sequence continued in relation to the required number of training sessions, which depended on the duration of the relative treatment period in the St. Mauritius hospital.

5.2.5 Measurement of Training Performance

The primary outcome of this trial is represented in the measurement of the training performance on the WCBT. Activity measurements were recorded by corresponding memory sticks that were connected via USB port directly to the training tool. Recorded parameters were: (1) distance covered (in km), (2) duration (in minutes) and (3) intensity (average watts). The primary outcome measure was training performance (in joules), which was gained through multiplication of intensity and duration of self-directed training (see Formula 1).

$$performance\ (J) = average\ power(w) \times\ duration(s)$$

Formula 1: **Calculation of training performance**; J = joules; w = watt; s = seconds

Training variables and calculated training performance were reported back to participants in the next pre-training meeting. Training data were collected and entered to the measurement report (see annex IV). Further, the examiner provided a detailed explanation on how to raise the training performance. Thus, patients were enlightened that their training results could be raised by extending the duration of a training session, by exercising at a higher level of resistance and by cycling faster. The examiner did not set any target. Placement of parameters was exclusively set by participants by using the color screen of the WCBT, which provided a touchpad to control the parameters and to track the training data (see Fig. 6). Patients could choose a resistance level and set the duration of the exercise. The modifying of parameters was possible throughout the whole training session. A higher resistance level, ranging from one to fifteen on the scale, resulted in a higher average power of Watts and therefore in higher training intensity. Parameters shown on the screen during an exercise were: (i) pedaling speed (per minute), (ii) heart rate (if wearing the corresponding cardio pulse set) and (iii) calories burned (kcal).

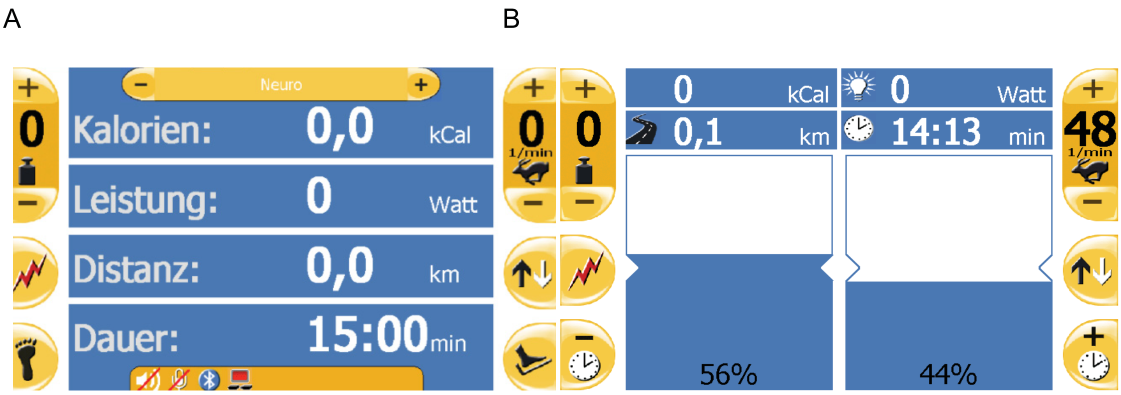


Fig. 6: **Display of the WCBT**; min = minutes; Kcal = kilo calories; km = kilometers; (A) Start screen; participants could choose training parameter (if a pulse band was worn by the patient, pulse is also displayed); (B) Training data can be tracked by the participants (distance covered, length of training, effort in Watts, burned calories and pedaling speed in round per minute). Two parameters the resistance level (represented by the weight symbol in the upper left corner) and the duration of exercise (represented by the plus and minus symbol in the right and left lower corner) can be adjusted. Left and right bar show the intensity of pedaling of the right and the left leg in percentage; for more details see text; by Thera-Vital Vital (by Medica Medizintechnik GmbH). ©Medica Medizintechnik

5.3 Data Processing

5.3.1 Preprocessing of primary outcome measure

Since average levels of training performance differed considerably across participants, training performance was standardized (z-scored) prior to statistical analysis. Therefore, primary outcomes (training performance) were z-transformed. Z-transformation is a dispersion measure using standard deviation to describe a statistical characteristic. In this case, it is a useful statistical tool to classify individual values from different samples of heterogeneous groups (in this case, different participants including males and females with different performance abilities). By z-transforming, values without dimensions are received, which allow a comparison of individual values (x_i). These z-scored values (z_i) define the division of the mean value ($\bar{x}$) of the sample by the number of standard deviations (s).

$$z_i = \frac{x_i - \bar{\mathrm{x}}}{\mathrm{s}}$$

Formula 2: **Z-transformation**; z_i = z-scored value; x_i = single value; $\bar{x}$ = mean value of the sample; s = standard deviation.

5.3.2 Further Collected Measures

5.3.2.1 *Secondary Outcome: Borg RPE Scale*

Following each training session, participants were asked to rate their exertion and effort of their earlier training session. Therefore, a ratio scaling method namely the Borg rating of perceived exertion (RPE) scale was provided [17]. The scale is a tool for rating a subjective training intensity to estimate different perceptions of exertion. Also, other reference values like breathlessness or muscle pain can be derived from the scale [164]. Borg's findings suggest further that subjective effort scales with the increase in heart rates [162]. While the scale is defined in single items from 6 to 20, the correlating heart rates range from 60-200 beats per minute [17, 165]. The lowest rating of 6 is defined as no exertion, while the highest rating of 20 is defined as maximum exertion. Also other scales exist, the scale from 6-20 is especially recommended for use in standard cycling performance because it scales well with the perceived exertion [166]. Use of the scale is also recommended because of its reproducibility and simplicity [164, 166]. Prior to exercises, participants were instructed how to use the Borg scale correctly (see annex VI). This instrument allows an evaluation of training performance and a classification of each training session for each participant as a secondary outcome. The study project intended to examine perceived exertion with no a priori predictions, but to find possible modulating factors in addition to competition. Moreover, the RPE scale was used in combination with secondary measure increase in heart rate (%maxHR) to guarantee health-related security to determine e.g. risks of overstressing during training sessions and in performance tests.

5.3.2.2 *Secondary Outcome: Heart Rate Measurement*

Heart rate measurement was conducted by use of chest bands (polar chest band, POLAR) during the exercises and by pulse measurement prior to the training session (Omron M5-I,,OMRON, Healthcare Europe). Recorded variables were the mean and the maximum heart rate during a training session, as well as the resting heart rate pre-exercise. Mean heart rate during performance had been collected, but was not used for analysis. Secondary outcome, the percentage of maximum heart rate (%maxHR), in the following referred to as increase in heart rate, was then calculated by use of Formula 3. The formula corresponds with knowledge of the linear relation of heart rate to oxygen uptake during an increase of intensity during exercises [79, 163] (see 4.3.2). Analysis was performed without any a priori predictions in relation to main predictors (training performance, experimental conditions, and the time), while intra-individual analyses helped to identify possible side effects. Moreover, in combination with perceived exertion measure, it helped to guarantee health-related security during exercises and performance tests.

$$HRincrease: \%HRmax = (100 \div HRmax) \times \; HRmean \; in \; \%$$

Formula 3: **Calculation of secondary outcome HRincrease:** $HRincrease$ = the increase in heart rate (percentage of maximum heart rate); HRmax = maximum heart rate; HRmean = mean heart rate; $\%maxHR$ = percentage of maximum heart rate; HRrest = resting heart rate. Based on linear relation between heart rates and oxygen-uptake under increasing demand [79, 163].

Moreover, measured heart rates were used to calculate individual limits for the increase of stress during training sessions for the monitoring of dangerous overstraining especially in combination with pre-existing medical risk factors like arrhythmias or high blood pressure. For this purpose, the modified Karvonen formula was used. The Karvonen formula allows calculation of a safety cut-off (HRSC), which corresponds with the percentage (in this case 70%) of the maximum oxygen uptake [167]. It is therefore possible to calculate a percentage of heart rate reserve, which corresponds with the theoretical oxygen uptake in linear relation under increasing intensity of stress during an exercise [79, 167].

The safety cut-off (*HRSC)* was determined prior to each training session. If HRSC was reached, the stress level was reduced immediately by the adaption of training parameters e.g. by reducing the pedaling speed or the level of Watts on the bicycle trainers. The formula for calculation of HRSC is presented below (Formula 4). This limit (HRSC) was generated by the heart rate at rest (*HRrest)* and an individual heart rate that was evaluated by the individual age. Integrating the factor age is linked to the fact that the reachable maximum heart rate decrease among older people as well as the range of therapy-effective stress level as presented in 4.3.2 [24]. Also, respecting the antihypertensive effect of beta-blockers, the safety cut-off was set lower (0.49) if a participant received this medication.

Without ß-Blockers: $HRmax = 208 - (age \times 0.7)$

With ß-Blocker: $HRmax = 208 - (age \times 0.49)$

$Hrmax\Delta = HRmax - HRrest$

$HRSC = HRrest + HR\Delta max$

Formula 4: **Calculation of safety cut-off (HRSC);** HRSC = safety cut-off; ß-Blockers = beta-blocker medication; HRmax = maximum heart rate during a training session (measured); HRrest = resting heart rate; HRΔmax = increase in heart rate during a training session (calculated); modified from Karvonen-formula, based on [168, 169].

5.3.2.3 *Total Activity*

Total activity of participants was recorded using the activity tracker (ViFit Activity Tracker, Medisana AG, Germany). Results were not analyzed in this study.

5.3.3 Statistical Analysis

The main objective was to determine the effect of experimental condition on primary outcome training performance. The secondary outcome 'perceived exertion' and the increase in heart rate were tested without specific predictions on its behavior in relation to the main predictors: time, experimental condition and training performance. Two data sets were created. The first contained standardized training performance for each participant and each experimental condition with the corresponding secondary measures (perceived exertion and %maxHR). The second data set contained mean values in Joules for the experimental condition baseline, feedback and competition for each participant. Three generalized estimating equation (GEE) models were used for the analysis of primary and secondary outcomes on the first data set. The second data set was used for analysis of variance (ANOVA) with repeated measures, also examining primary outcome training performance.

i) Primary Outcome: Training Performance

Collected data were analyzed by the use of the software package GEE model. GEE is an analysis method that can independently handle the investigation of repeated measurements for each single participant with simultaneous multiple factors and unknown cofactors [170-172]. Also serving as a linear regression model, the GEE model analyses the impact of different possible factors on the observed subject at once. The advantage of this method compared to an analysis with ANOVA is that GEE is also able to deal with missing values like the time interval between measurements and violation of sphericity [170-172]. It was therefore possible to compare outcome variables intra-individually across experimental condition. To identify the overall power of competition, each control condition was compared with the intervention condition (competition vs. baseline, competition vs. feedback). Comparison of competition and high-level-control condition feedback helped to isolate effect of competition from components of feedback. This analysis was deemed to examine the mechanism of a possible performance increase during intervention condition.

Analyses were started with a GEE model evaluating the effect of experimental conditions on training outcomes. Z-scored training performance served as a linear response measure. This measure was examined in relation to the predictors: experimental condition (baseline, feedback, and competition given as a category) and the time in days passed since the first recordings. The variables participant's identification code and the number of training sessions were used for within- and between subject identification in all subsequent GEE models. In addition, an unstructured working correlation matrix was applied.

An additional analysis of variance with repeated measurements was performed on the non-standardized training performance in dataset 2. The three experimental conditions (baseline, feedback and competition) were entered as categories of repeated measurements and unstandardized training performance served as depended variable. The test contained a Mauchly-test for assessment of the violation of sphericity. Further, a post-hoc analysis with Bonferroni was adjusted to compare the main effects (experimental conditions).

ii) Secondary Outcomes

Then secondary outcomes were analyzed with no a priori predictions. However, intra-individual analyses by the use of two more GEE models helped to identify possible modulating factors to a performance increase through competition. In each case, perceived exertion and %maxHR served as linear response measure. Both sets of analyses assessed the relation of each secondary outcome with the predictors time, experimental condition and training performance. Again, time was represented by the number of days since the beginning of measurements.

A third statistical analysis was performed on the performance tests, assessing results by three categories (referred to as overall assessment): "improvement", "worsening" and "no change". This overall assessment was obtained through a simple comparison of the change in performance capability between the pre- and the post-performance test. Prior to statistical analysis, categories were defined: (i) improvement was applied if a participant reached a higher intensity in the pre-performance test in comparison to the one prior to the first measurements (see annex VIII). If the same level was reached in both tests, the mean heart rate during the last fully completed step of intensity was assessed. A lower heart rate (±2) during the same effort (on the same step) was valued as improvement of performance. (ii) Reaching in turn a lower step as in the pre-performance test was classified as “worsening”. Here, a comparison of the mean heart rate during the last fully completed step of watts occurred if the same step was reached in both tests. A heart rate higher than ±2 was also determined as a worsening. (iii) If a participant reached the same step in the pre- and in the post-performance test and the mean heart rate did not differ either, the third category (no change) was determined. Chi-square test analyzed comorbidities of patients in the sample upon a correlation with the overall assessment of the tests. Descriptive analysis was then performed on the resulting data, summarizing the overall assessment of the performance tests, the termination of the test (rule-consistent or early termination) and the Borg scale scores (by self and external assessment of the perceived exertion during the performance tests). A bivariate Pearson-correlation analyzed the association of both kinds of assessment.

SPSS Version 23 was used for statistical analysis (IBM SPSS Inc., Chicago, IL). Analyses were applied two-tailed and alpha was set to .05.

6. Results

The following chapter provides results of the study analyzing primary outcome training performance across the experimental conditions baseline, feedback and competition, and the secondary outcomes' perceived exertion and the increase in heart rate. Finally, this chapter presents a descriptive analysis of the performance test.

6.1 Primary Outcome: Effects of the Experimental Conditions

Analysis by the use of the GEE model for the sample of 63 participants on the WCBT showed that experimental condition (main effect: Waldχ^2 = 13.86 p = .00) scaled positively with training performance (see Table 2). In contrast, the predictor time (main effect: Waldχ^2 = 2,22 p = .14) was not significant for training performance. Parameter estimates for predictor time showed no effect on training performance with time passed (in days) since the start of recordings: ß = .020 (CI 95%: .01 - .05, p = .014, SD = .01), indicating no change in training performance over time. By analyzing experimental conditions competition vs. experimental control condition baseline, a strongly significant influence of condition competition on training performance could be shown: ß =. 13 (CI 95% = .06 to .21, p = .00). This indicates a significant rise in training performance during a competition term (see Table 2, Fig. 7). In contrast, second control condition feedback had no significant impact on the factor training performance compared to baseline ß = .03 (CI 95% = .08 to .13, p = .61).

	β	SD	CI 95% from	to	Wald $\chi^2$2	df	p
(constant term)	-.30	.08	-.45	-.16	16.40	1	.00
competition	.13	.04	.06	.21	11.15	1	.00
feedback	.03	.05	-.08	.13	.27	1	.61
baseline	0	.	.	.	.	.	.
time	.02	.01	-.01	.05	2.22	1	.12
(Scala)	.94						

Table 2: **Effects of experimental conditions baseline, feedback and competition**: ß = regression coefficient, SD = standard deviation, CI 95% = confidence interval, hypothesis test: p = significance, df = degree of freedom, Wald χ^2 = chi-square distribution, alpha-level was set at .05; Parameter estimates for z-scored training performance are shown in the table above. Regression coefficient ß increased for experimental condition competition. Hypothesis test was significant with p = .00 in comparison to control condition baseline. No significant increase of training performance was found for control condition feedback (p = .61);

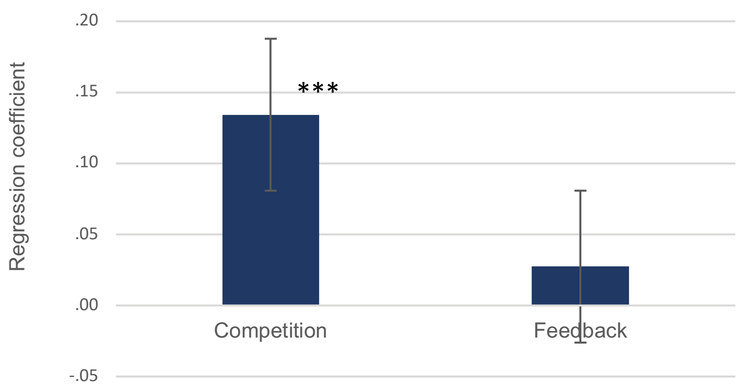


Fig. 7: **Comparison between the effect of feedback and competition upon training performance**: Error bars represent the SEM (standard error of the mean); regression coefficient = beta-coefficient from GEE model, compared to baseline (dimensionless); *** = p < .011; the effect of experimental condition upon z-standardized training performance via ß-coefficient gained from GEE model. Training performance is shown in comparison to control condition baseline. ß-coefficient is below alpha-level for competition (p = .00), but not for feedback (p = .61). Standard deviations (SD) for competition is SD = .04 and for feedback SD = .05.

Mean difference between competition and feedback was significant with competition term in comparison to feedback condition (mean difference .11, SD = .05, p = .02) and even greater difference was found between competition and control condition baseline (mean difference .13, SD = ,04, p = .00) (see Fig. 8).

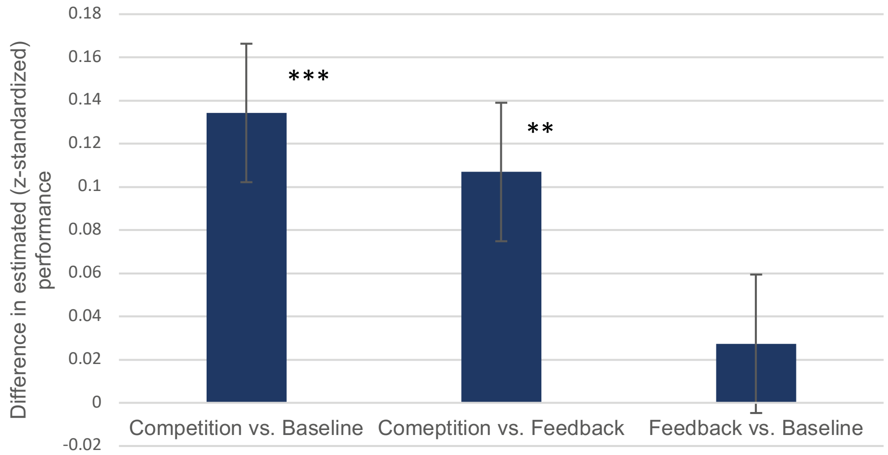


Fig. 8: **Pairwise comparison of training performance in the experimental conditions:** Error bars represent the SEM (standard error of the mean); regression coefficient = beta-coefficient from GEE model, compared to baseline (dimensionless); *** = p < .011; ** = p < .01; the Figure is based on mean difference of z-standardized training performance estimated for 12.43 days since measurements began. Pairwise comparison was performed on model-estimated, z-standardized training performance measured in the three experimental conditions. Mean difference of "Competition vs. Feedback" (p = .018) and "Competition vs. Baseline" (p = .001) is significant. Group "Feedback vs. Baseline" was above the alpha-level of .05 (p = .211).

Fig. 9 shows results of a pair-by-pair comparison, performed by the GEE model analyzing competition condition with feedback condition. Competition showed the average z-scored training performance of .08 (SD = 2.22) and a significantly lower average training performance was measured during feedback conditions of -.03 (SD = 2.20) at an average time of 12.43 days passed since measurements began. Lowest mean training performance was reached in the baseline condition. Fig. 10 shows an individual training performance of a single participant through the three experimental conditions and the time in days. After six training sessions, training performance was the highest in the competition condition. Results are presented with z-standardized values (grey) and raw values (blue). The total result of the GEE model based on the non-standardized training performance was p = .00 (Waldχ^2 = 13.86), also indicating a significant effect of the experimental conditions on the training performance.

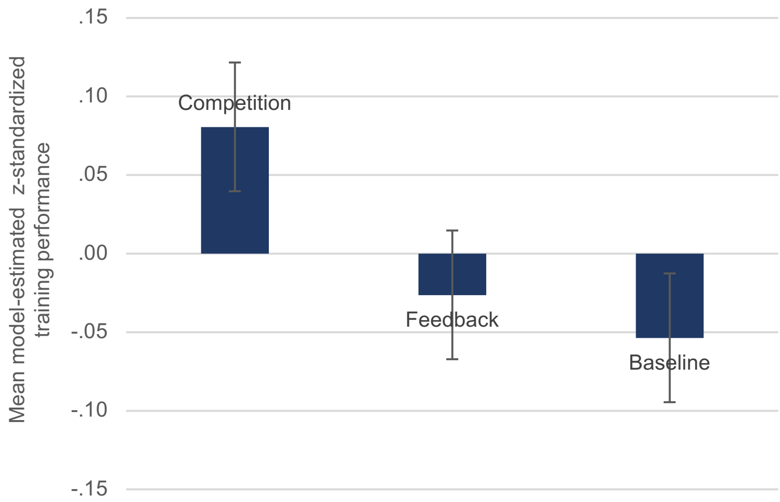


Fig. 9: **Mean training performance in the three experimental conditions:** error bars represent standard error of the mean (SEM) defined by ±2; training performance is presented in z-standardized, model-estimated mean values (by GEE model); the figure presents z-standardized training performance (mean values) through experimental conditions defined as baseline, feedback and competition estimated for 12.42 days since measurements began.

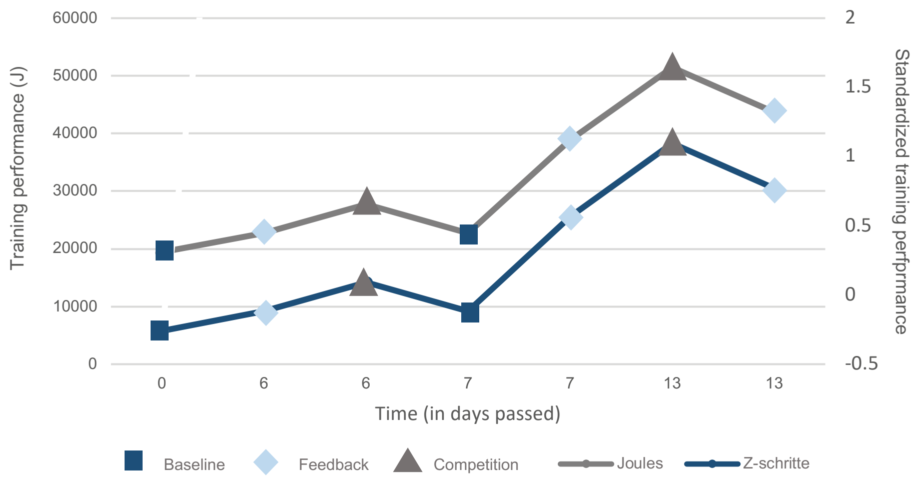


Fig. 10: **Performance history of a single participants**: J = Joules; standardized training performance = dimensionless training performance gained through z-standardization; performance history of a single participant (identification number 121) through experimental conditions: baseline, feedback and competition is presented. Training performance is given in Joules on the primary (grey graph) and z-standardizes values on the secondary y-axis (blue graph). Time in days since measurements began is shown on the x-axis. Training performance increased during competition conditions.

In addition to analyses by the use of the GEE model, a general linear model for repeated measures was used for the direct comparison of the experimental conditions baseline, feedback, and competition, based on the final sample (n = 63) and the mean training performance of each condition and for each participant. The mean training performance in Joules (non-standardized) was highest in the group of the experimental condition competition (mean competition = 25293.32 J, SD = 19764.80) compared to the mean values of the two control conditions (mean feedback = 22578.80 J, SD = 18696.04, mean baseline = 21641.54 J, SD = 16834.51). The mean values of the three groups of experimental conditions are presented in Fig. 11. as a linear increase in training performance (A) and as boxplots (B). What is striking about the figures is the clear trend of increasing training performance during the competition condition, which is shown in Fig. 11 A. In Fig. 11 B, the highest maximum values were reached during a competition condition. Also, most of the data in the competition condition are in the upper quartile above the median. Two participants of the final sample account for outlier values.

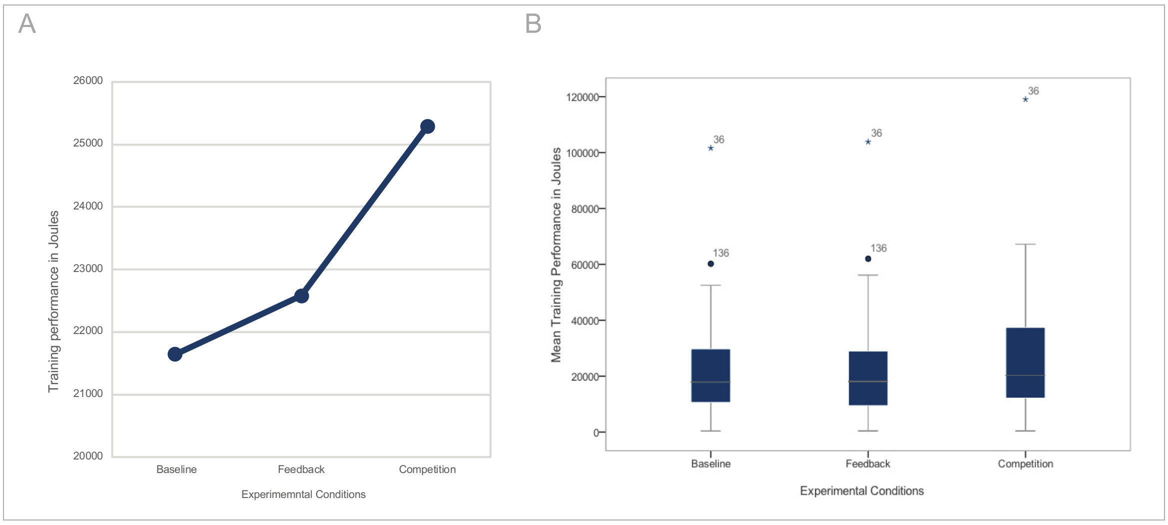


Fig. 11 : **Training performance across the experimental conditions:** error bars represent the standard error; p = .00; * = outliers with participant's ID number; J = Joules; the Figure shows the experimental conditions: baseline, feedback, competition on the x-coordinate. The y-coordinate shows the training performance in mean values for each experimental condition in Joules. (A) The Figure shows a significant increase in the mean training performance in the experimental condition competition; (B) mean training performance performed in each training performance is presented in boxplots; outliers are marked with the participant's identification number; outlier values were performed by two participants.

Multivariate tests showed an overall significance of p = .00. The Mauchly-test was used to assess the violation of sphericity. Results obtained from this analysis were not significant p = .44. Therefore, the null hypothesis was rejected and no violation of sphericity was expected.

This result is below the ∝-level of .05 (F = 11.66, p = .00), which indicates a strong difference between the three experimental conditions. Post-Hoc analysis based on Bonferroni revealed a direct comparison of the experimental conditions. It is apparent from Table 3 below that no significant difference between the experimental conditions baseline and feedback (p = .81) was found. However, supporting results gained through the GEE model, a significant association was found with the experimental conditions competition and feedback (p = .00) and with competition and baseline (p = .00). Supporting the hypothesis, training performance increased during the competition term in comparison to the control conditions (feedback and baseline).

The mean differences of training performance (mean values of training performance in the three groups of experimental conditions) differed strongly among groups. The greatest difference was revealed between the two experimental conditions competition and baseline (= 3651.78 J, SD = 730.02, p = .00). Also, a great difference was found between competition and feedback (= 2714.52 J, SD = 781.76, p = .00). No significant difference was found between control conditions feedback and baseline (= 937.26, SD = 841.30, p = .81) (see Table 3).

Condition (1)	Condition (2)	Mean difference (J), (1-2)	SEM	p	Ci 95% from	to
Baseline	Feedback	-937.26	841.30	.81	-3007.42	1132.90
	Competition	-3651.78	730.02	.00	-5448.13	-1855.44
Feedback	Baseline	937.26	841.30	.81	-1132.90	3007.42
	Competition	-2714.52	781.76	.00	-4638.17	-790.88
Competition	Baseline	3651.78	730.02	.00	1855.44	5448.13
	Feedback	2714.52	781.76	.00	790.88	4638.17

Table 3: **Pairwise comparison of experimental conditions;** J = Joules; SEM = standard error of the mean, p = significance, CI 95% = Confidence interval with upper and lower bound of 95%; The table shows a pairwise comparison of the three experimental conditions baseline, feedback, competition, performed by ANOVA.

6.2 Secondary Outcomes

6.2.1 Analysis of Perceived Exertion

The correlation between perceived exertion (Borg scale) and standardized training performance, time and experimental condition was tested using the GEE model. A total of 636 measurements were included in this analysis. The average value on the Borg scale rated by patients was 13 (mean value = 12.51) with an average z-standardized training performance of .00 at an average of 12.43 days passed since the recording of the first training session.

Perceived exertion co-varied with the training performance (Waldχ^2 = 8.64 p = .00) as presented in Table 4. No association was found between perceived exertion and time passed (Waldχ^2 = .16, p = .69) or between perceived exertion and the experimental condition (Waldχ^2 = .86, p = .65). Therefore, it can be assumed that perceived exertion was not influenced by time- or practice-related side effects. Overall, as shown by the parameter estimates, the predictor time ß= .01 (p = .69, SEM = 014, CI 95% from -.00 to .02) did not affect the value chosen on the Borg scale.

Source	Wald χ^2	df	p
(Constant Term)	888.43	1	.00
Experimental Condition	.86	2	.65
Time	.16	1	.69
Training Performance	8.64	1	.00

Table 4: **Perceived exertion in relation to the three main predictors;** df = degree of freedom, p = significance, Wald χ^2 = Wald-Chi-Square distribution; the table shows the results of the test on the model effect, performed by the GEE model.

6.2.2 Analysis of the Increase In Heart Rate

A sample size of n = 32 patients was used for the following statistical analysis. Measurements of n = 250 (39.3%) were included. Statistical analysis showed that the mean value of %HRmax was 57.35% (SD = 9.76) with an average of 9.23 days (SD = 9.04) passed since measurement began and the average z-standardized training performance was -.09 (SD = .70). The increase in heart rate ranged from 36% at the lowest to 85% at the highest. The GEE model was used to investigate the correlation between %HRmax and the main predictors: experimental conditions, time and z-standardized training performance. As presented in Table 5, analysis revealed a significant main effect of %HRmax and training performance (Waldχ^2 = 8.62, p = .00). No significance was found between HRincrease and the other main predictors namely time (Waldχ^2 = .75, p = .39), and experimental condition (Waldχ^2 = .71, p = .70).

The estimated parameters for the predictor training performance showed significant positive scaling with ß= 5.03 (p = .00, CI 95%: from 1.67 to 8.40, SEM = 1.71). No significance was revealed for the predictor time ß = -.11 (p = .39, CI 95%: from -.37 to .15, SEM = .13). Also, predictor experimental condition feedback ß= -.68 (p = .41, CI 95%: from -2.27 to .92, SEM = .82) and competition ß= -.35 (p= .70, CI 95%: from -2.17 to 1.47, SEM= .93) had no significant influence on %HRmax in comparison to control condition. Taken together, these results suggest that there is an association between the increase in heart rate and training performance, but not with the two other predictors: time and experimental condition. Thus, no time-or practice-related side effects were found by analysis.

Source	Wald χ^2	df	p
(Constant Term)	1162.72	1	.00
Experimental Condition	.71	2	.70
Time	.75	1	.39
Training Performance	8.62	1	.00

Table 5: **Effect of Predictors on the Increase in Heart Rate**: df = degree of freedom, p = significance, Wald χ^2 = Wald-Chi-Square distribution; increase in heart rate = the percentage of maximum heart rate; the table shows the results of the test on the model effect, performed by the GEE model.; the effect is significant for the term training performance (p = .00), but not for the terms time (p = .39) or experimental condition (p = .70).

6.2.3 Analysis of Performance Tests

A total of n = 30 completed performance tests, performed by 17 females and 13 male participants, were analyzed. The average age in the final sample was 72.87 years. Comorbidities of patients in the final sample were represented by 13 participants that were overweight and 3 that were adipose. Furthermore, 14 participants were taking the medication ß-Blockers (46.7%) while they undertook the pre- and the post-performance test. The average time passed between the first and the second performance test was 23.8 days with a minimum of 8 and a maximum of 45 days. A chi-square test analyzing the risk factor of ß-Blockers ($p = .96$), Body Mass Index ($p = .42$), gender ($p = .96$) and age ($p = .78$) in the sample did not reveal a significant relation between an improvement in overall assessment of performance tests. Expected and observed frequencies did not diverge strongly enough.

As presented in Fig. 12, descriptive analysis of the main effect showed that in total 60% of participants improved their cardio-respiratory fitness after the pre-performance test while 33.3% were classified as “worsening”. 6.7% of patients showed “no change” in physical fitness afterwards.

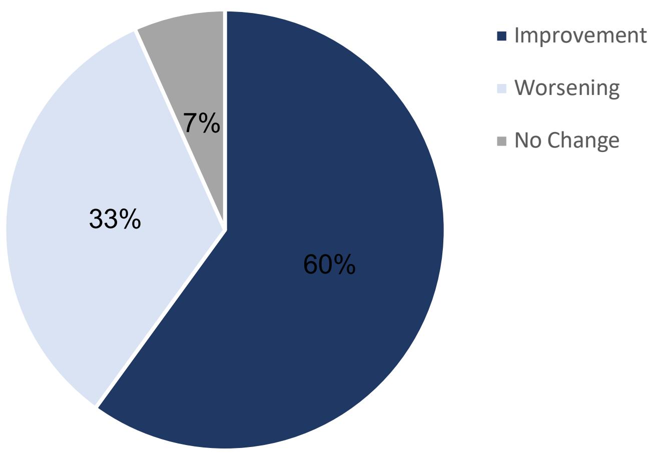


Fig. 12: **Result of performance tests**: Improvement = Increase in physical fitness (60%); worsening = decrease of physical fitness (33%); no change = no modification in performance capability (7%); The figure above provides a pie chart presenting results of the overall assessment after pre- and post-performance tests.

The pre-performance test was completed rule-consistently by 60% and stopped earlier by 40% of the participants. A total of 46.7% of patients completed the post-performance test consistently abiding by the rules. Post-performance tests were stopped earlier by 53.3% of the sample. Thus, a slight increase in a stop of the test by patients (non-rule-consistently) is recognizable. Participants that were assigned to classification two ("improvement") after the overall assessment of pre-and post-performance tests consisted of similar percentages. One half n = 9 (50%) of the total (n = 18) "improved" by reaching a lower mean pulse in the post-performance test compared to the mean pulse in the pre-performance test. The other half of the sample n= 9 (50%) reached a higher step of intensity in the post-performance test in comparison to the pre-performance test. The highest step of intensity (75 Watts) was completed by half (50%) of all participants during the pre-performance test. In the post-performance test, 53.3% of the participants completed the last and highest step of intensity (see Table 6).

A Pre-Performance Test			Total	**B** Post-Performance	Total
Highest completed step of intensity (in W)	0	n (%)	1 (3.3%)		1 (3.3%)
	Step 26	n (%)	5 (16.7%)		7(23.3%)
	Step 50	n (%)	9 (30.0%)		6 (20%)
	Step 76	n (%)	15 (50.0%)		16 (53.3%)
Total		n (%)	30 (100.0%)		30 (100%)

Table 6: **Steps of Intensity Completed in Performance Test**: n = total number of cases; W = Watt (international unit); % = percentages; n = number of cases; the table shows highest completed step of intensity by patients during the (A) pre-performance test and (B) post-performance test.

Analysis of perceived exertion showed a slightly higher mean score on the Borg scale rated by patients themselves (14.03) in comparison to external assessment (13.67). However, maximum and minimum scores differed more notably between patients and the examiner as more extreme scores were assessed by patients. On a score of 6 to 20, the maximum score rated by patients was 19 and the minimum score was 11. The examiner assessed the perceived exertion of participants (external assessment) from 7 to 17 at the highest based on the Borg scale. An analysis of a bivariate Pearson correlation was performed on pre- and post-performance test to examine a statistical relation between the two assessments of perceived exertion (by patients themselves and the examiner) using the Borg scale. Results of the pre-performance test indicated a positive linear correlation between the two variables assessment by patients and external assessment of perceived exertion (r = .635, p = .000 for the two-tailed alpha level of .01), as presented in

Fig. 13. The Pearson correlation is significant, and the effect size of r = .635 is to be assessed as strong. There is a slight tendency of stronger positive correlation in the post-performance test compared to the pre-performance test.

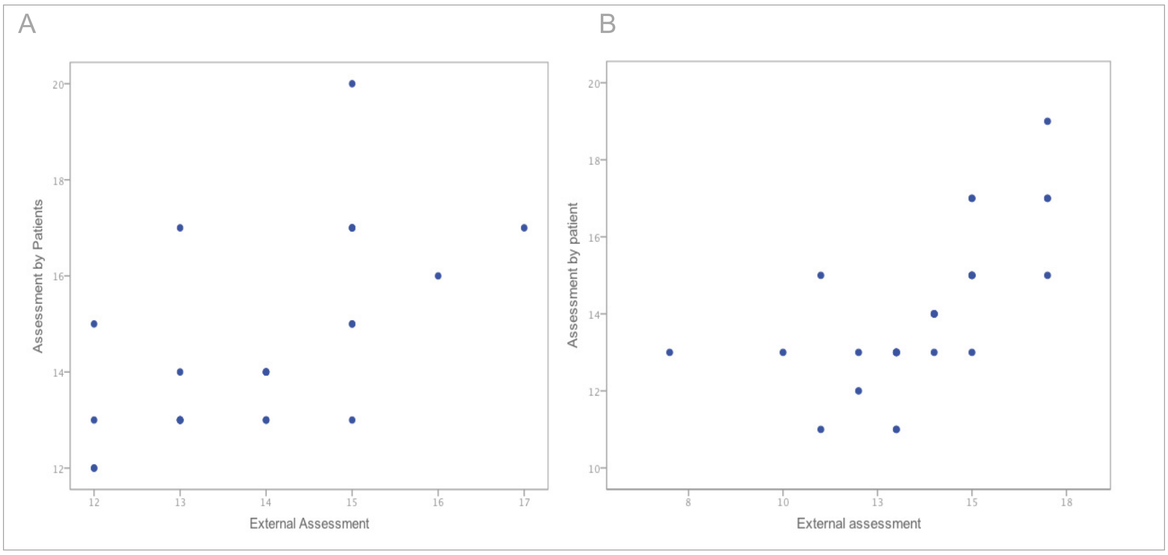


Fig. 13: **Comparison of external and subjective 'perceived exertion':** r = .635; p = .000; two-tailed alpha-level = .01; Assessments by patient and by the examiner; Borg scale ranges from 6-20 (6 = not difficult at all, 20 = extremely difficult); the Figure above shows results of bivariate Pearson correlation analysis between the two variables: external assessment of exertion and subjective assessment of patients themselves. (A) correlation in the pre-performance test (B) correlation in the post-performance test; both variables show a significant (p = .000) positive linear correlation. Effect size is strong (r = .635).

7. Discussion

In the following chapter, primary and then secondary outcomes will be discussed in relation to the study questions. The next chapter will deal with potential negative consequences of the use of competition in neurorehabilitation and will point out questions for future research. Lastly, a conclusion of findings is provided.

7.1 Discussion of Primary Outcome : Training Performance in the three Conditions

Notwithstanding post-stroke impairments in terms of functional deficits and deconditioning (see 4.2.5), training outcome potential of stroke patients is similar to outcomes reached by same-age healthy people [63]. In a randomized, controlled trial, hemiparetic stroke patients performing graded aerobic exercise over 10 weeks were analyzed [173]. Results showed that participants significantly increased their exercise tolerance through training. Participants improved variables like intensity and duration of exercises, cardio-respiratory-fitness, as well as their sensorimotor function [173] in comparable dimensions reachable by study participants who are healthy [63].

However, thus far most research on competition investigated healthy people (see 3.4.3. and Fig. 2). Sports competition was introduced in various disciplines and with wide-ranged investigation methods. In sport disciplines, competition evoked improvement in physical performance, for example in the field of rope skipping [174], golf [175], and running [117]. In economic studies, commercial sales have been investigated [16]. Recent studies from the fields of biology and psychology examined upper limb performance by the use of hand-grip forces [14, 144]. Participants performed 21 seconds longer on a physical contraction task during an experimental condition, competition [14]. All approaches have in common that under competitive conditions an enhancement of physical or cognitive performances and effort was achieved. Thus, to find beneficial scopes of applications for the factor competition, it is crucial to test their practicality upon impaired persons as well. This was the basic aim of the present study.

In this analysis, training performance was compared across the three experimental conditions intra-individually. The primary issue of the study was to investigate whether competition improves the physiotherapeutic measure self-directed training in in-patient stroke patients in neurorehabilitation. The second issue was to prove how powerful this effect would be. The third issue asked how the underlying mechanism of the effect would be composed. This study hypothesized that adding the factor competition would increase self-directed training in stroke patients.

i) Conception of the Test

The conception of the study was chosen to create ideal basic conditions to identify the effects of competition upon training performances during self-directed training. Recommendations stated by Deci and Ryan to increase motivation for tasks [111] were considered.

They firstly suggested an "unauthorized" environment for performance. It is assumed that this environment was created by way of self-directed training because self-directed training was performed voluntarily by the participants and without direct supervision by the examiner or therapists. Through the information that training results were recorded for each training session, and that they would receive results in the following pre-training meeting, participants were aware that training outcomes depended exclusively on their own performance [111, 124, 159-161].

Secondly, Deci and Ryan suggested creating an adequate agenda with the chance of success. Thus, in the intervention condition competition, participants were informed that they were competing against an opponent that matched their age, gender and exercise capability [124, 159-161]. This information is important because there is mounting evidence that only the chance to win has a motivating effect [124, 159-161]. Therefore, a cover-up story created a more or less equal opponent to prevent that participants from losing motivation right from the beginning. Thus, it can be assumed that participants felt that they had a realistic chance of winning.

It has been found that only winning a competition and not losing can be motivating [e.g. 176, 177, 178]. Hence, the participants were told to have outperformed their opponent. However, the fictional competition was won by a short margin. This fact was added to the cover-up story to create credibility. It was intended to create the impression that the opponent was truly well-matched and proper in the level of demand [111]. Winning the competition should not be too easy and participants should feel that it is necessary to exert oneself because otherwise the opponent could win the next time.

The third recommendation included giving feedback as a theoretical reward. For this reason, again, a cover-up story was used. During high-level control condition feedback, participants received feedback about their performance. In the interventional condition competition, elements of positive feedback the theoretical reward of being told to have won the competition - were used [111]. Hence, there is an overlapping of mechanism between feedback and competition. For this reason, high-level control condition was added to separate effects.

In the control condition baseline, recordings of training performance were covered and no feedback was given. This condition was deemed to represent the regular self-directed training. This condition illuminates the fact that these rehabilitation measures usually take place unsupervised, without controls, recording of training data or feedback on the training success (see 4.3.4).

As mentioned in 4.4.2, the effect of competition is situation-related [107]. The cover story thus was determined to create an accurate environment [124, 159] to fully unfold the effect of competition and to receive full experimental control over outcomes of each experimental condition.

The order of conditions was randomized to reach an even distribution of disturbance and ensure the exclusion of time-series effects. Orders were arranged in computer-generated blocks to ensure receiving equal numbers of each experimental conditions. Additionally, it was possible to receive preliminary results. These orders were then assigned in accordance with the temporal sequence of recruitment of participants. This way, the order of conditions was not fully at random but pseudo-randomized.

ii) Discussion of Method

As mentioned before, characteristics of competition are congruent with giving positive feedback. In both conditions, participants were aware of being recorded and of receiving feedback after the exercise. Psychological theories assume that social support by others is a positive incentive for a certain behavior (see *self-determination-theory;* 4.4.1) [107, 179]. Hence, positive feedback also serves as an external benefit.

Moreover, feedback is deemed to influence motivation positively in neurorehabilitation. As laid out in the introduction, motivation is a key aspect of *task-oriented motor relearning* in modern evidence-based strategies in neurorehabilitation. It embodies an interactive process that takes place step-wise [180] under increasing demand [80]. For instance, walking ability is an important aim for stroke patients in neurorehabilitation to regain independence and self-determination. Here, the level of difficulty can be raised gradually - called *shaping*. This term also includes the idea that a motion sequence consists of different sub-movements. Step by step, after relearning these elements under increasing demands, the single motion sequences can be put together like a puzzle [72]. Interestingly, positive feedback by physiotherapists is found to affect the patient's relearning process positively [181, 182]. Studying the reasons for this effect, research found that positive feedback after successful attempts promotes a patient's motivation [183]. Supporting this conclusion, missing encouragement by therapists is identified as one reason for the poor implementation of self-directed training by patients [13]. Thus, to reveal the full potential of competition, a comparison of "competition vs. baseline" and "competition vs. feedback" was performed in this trial. In doing this, the effects of competition could be separated from effects caused by feedback.

Taking a critical look at time and place of data collection, it is to note that measurements took place exclusively on the weekends during leisure time. The required number of training sessions was at least five. Thus, great time intervals between training sessions developed. This led to problems for two reasons. Firstly, participants were sometimes discharged early from hospital, before reaching the required number of at least five training sessions. A remaining stay of at least two weeks was required for this purpose. Thus, data of the participants concerned could not be analyzed. Secondly, this criterion could have led to an uneven number of recorded training sessions for each group of experimental conditions, which could have led to distorted results. However, block formation during pseudo-randomization of order of condition demanded an equal number of conditions after six training sessions. An uneven number of five training sessions was received from very few participants in the final sample.

The final sample consisted of approximately equal shares of both male and female participants. Beyond that, inclusion criteria were designed to create a preferably homogenous sample. However, it is to note that performance levels in the group were wide-ranged (see Fig. 11 B). The question thus arises whether results of single participants of the final sample are comparable. For this reason, a standardization of training performance was performed by way of z-standardization (see 5.3.1). After calculation, data were given as dimensionless values characterized in multiple standard deviations. Thus, it can be assumed that results are comparable within this final sample. Though, it is to note that no measurements and analyses of differences in performance level within the final sample (like, for example, differences between the male and female groups of participants) were performed. Moreover, as suggested by several theories on the origin of motivation, it cannot be excluded that single participants or even groups of participants were affected to a different extent by competition. Supporting this assumption, studies on neuro-biochemical processes (see 4.4.2) found that competitiveness is associated with the level of testosterone [147], which is expressed differently in males and females [149]. Moreover, it is known that there is a difference in the degree of competitiveness in males depending on the functional efficiency of gonads [153].

iii) Discussion of Results

Referring to the first study question, this study found evidence that self-directed training was significantly increased through competition (see e.g. Fig. 7, Fig. 8, Fig. 9, Fig. 10, Fig. 11). Participants performed self-directed training longer and with higher intensity. Thus, the findings of this study support those of former studies by proving that physical performance in unhealthy patients can be raised by adding the beneficial factor competition.

Secondly, the question was how strong the effect of competition might be. The increase in training activity was strongly significant in comparison to the two control conditions baseline and feedback (see Fig. 8). The findings of the current study do not support the aforesaid research on the effects of giving positive feedback. No significant increase in training performance was associated with the condition feedback in comparison to baseline and competition. Although mean training performance during feedback conditions was higher compared to those performed in a baseline condition (see Fig. 11 A), results were not able to sustain deeper analyses. Direct pairwise comparison of baseline and feedback showed that results performed in these two control conditions did not significantly differ from each other compared to performances during competitions (see Fig. 7). Results indicate that feedback has a positive impact in comparison to no feedback on performances, but competition was proven to be a much more powerful instrument for this purpose.

Thirdly, the question concerned the underlying mechanism of this effect. It is proposed that stimuli had been set through the cover story to "demonstrate abilities" by winning the competition [111, 184, 185]. This is underlined by the theory of "avoidance-goals" [155]. Performance could have increased because participants wanted to avoid losing [157, 158]. Another explanation is that participants avoided a decrease in social recognition and status [147, 156]. However, the latter is assumed to be not very likely because participants were always told they had won the competition.

Another possible explanation is that motivation was increased intrinsically. On the basis of theories from biology, Burguillo claimed, for example, that the enhancement of joy of the activity itself is a source of motivation [130]. Hence, through the competitive context, the enjoyment of self-directed training would have been increased.

It is also possible that the subjective benefit of self-directed training was augmented by the expectation of outperforming an opponent. Competition could have served as an additional extrinsic motivator which did not arise from the activity itself. This line of thought follows *benefit-cost framework* (4.4.1). This theory incorporates the assumption that participants evaluate intrinsic and extrinsic anticipated costs and benefits of self-directed training beforehand. This means that the value of self-directed training became greater because competition was added as an extrinsic incentive.

This pathway is also described by the benefits-cost-framework theory, proposing a variety of ways to increase motivation for a performance: i) increasing intrinsic motivation, ii) boosting the task with an additional extrinsic factor, iii) augmenting the expected benefit of an extrinsic factor of a task, iv) reducing expected costs of a task and v) reducing expected costs by ensuring a lack of an attractive second choice [107].

In this study, the focus was on approach three by increasing the extrinsic benefit by combining self-directed training with competition [107]. Anticipated costs of self-directed training could have been represented by the required expenditure of time for exercising during leisure time and the exhaustion post-exercise [31]. As benefits, the expectation of improvement in physical condition, mobility and general well-being [31] could have served as incentives as they are prime goals of neurorehabilitation [63] (see 4.3.1). Due to the special environment of neurorehabilitation, a mainly inner source of motivation as proposed by Burguillo was not assumed as likely.

Following this line of argument, a project by Studer et. al examined the effect of "joy of winning" [18-20, 31]. In this study, participants were competing against the same opponent twice. After being told they had won a competition twice in a row, physical performance was even higher in the second than in the first round. It is assumed that this effect was achieved by upgrading the task with an external profit [2, 31].

This assumption is also supported by findings from research on the neuronal level as mentioned in 4.4.2. The "winner effect" [122] is associated with an increase in testosterone, while losing hampers secretion [148]. Moreover, "winning" leads to a stimulation of processes in the rewarding system, which is associated with the medial prefrontal cortex [31, 137-142, 144, 186]. It is assumed that successfully competing against an opponent is a worthy ambition [144, 186] which raises motivation and consequently increases performance [31].

However, in which way motivation of participants increased during the present study cannot be answered for sure as no explicit testing was conducted. Origins and composition of motivation through competition may have been subject to individual and state-dependent differences [107].

In summary, it can be assumed by the results of this study that motivated behavior was anticipated by shares of both extrinsic and intrinsic factors. However, it is assumed that motivation was mainly modulated extrinsically by adding the factor competition. It is proposed that competition extended the benefit of the task by the way of the possible "victory" [18-20]. Thus, it is proposed that on the basis of the benefit-cost framework [107], the benefits of self-directed training in neurorehabilitation outweighed the costs and increased motivation.

Besides analysis of training performance in the three experimental conditions, primary outcome was assessed in relation to predictor time. Interestingly, findings by the first GEE model suggest that training performance did not improve over time (see Table 2). Due to the beneficial effects of cardio-respiratory exercises performed during self-directed training, an improvement in cardiorespiratory fitness might have been expected. Results of performance tests (see Fig. 12), which will be discussed in chapter 7.2.3, indicate that participants improved their cardio-respiratory fitness through endurance training in this study. It is interesting to note that single training results as presented in an exemplary way for a single participant in Fig. 10 show a trend of improvement when imagining a best-fit grade line. Studer et al. (2016) [31], using a similar study design and setting, found too that physical performance increased significantly over the training period. How do these results fit together?

Results of the analysis of training performance need to be interpreted with caution. The GEE model, which was used in this case, performs a linear calculation. Periods of measurements were very short in this study (on average 9 days), which may not allow strong graduation of training performance. Measurement intervals in the aforesaid study were shorter as they were performed every working day. Concerning performance tests, the difference might be that participants performed at their capacity limits. Thus, it might have created a high-contrast picture of the development in performance. Hence, due to the underlying methodology, effect may have simply not become obvious by statistical analysis.

iv) Possible Sources of Error

Possible weaknesses of test method are discussed in the following section. Training performance was measured in three experimental conditions. Conditions were categorized by different instructions that were given prior to training sessions by the examiner. No single-blinding was possible. Hence, this study design does not fully exclude the risk of manipulation by the examiner. Variance in the formulation of instructions may have influenced training performance. Comparability of experimental conditions would not have been given anymore. Also, it is possible that the mediation of instructions creates different effects depending on the person giving them. As laid out in the introduction (see 4.4.1), motivated behaviour is also influenced by social aspects [187, 188]. Different characters of participants may have been addressed differently and even if using identical formulations, different impacts may have been achieved. However, as instructions were strictly given as defaulted and always given by the same examiner, this occasion does not appear very likely. Therefore, extreme variation in the impact of instructions can be excluded.

Another possible source of error may have occurred due to measuring instruments. Training performance was recorded by computer-assisted bicycle trainers. Actual training performance could have been falsified because of measuring errors. For example, training performance could have been recorded by shorter time because computer or buffer stopped recording the data. As participants were exercising without direct supervision, manipulation of measuring tools was possible. However, as presented in Fig. 4, no data were lost due to measurement errors in the final sample. Also, no manipulation of training performances by both measuring tools or participants were registered in this study.

v) Conclusion

Summing up, it could be shown that competition increases training performance significantly during self-directed training on a WCBT. In-patient stroke participants in neurorehabilitation exercised more intensively and longer in self-directed training during a competition. Competition has been proven to be a more powerful instrument to improve training activity than giving feedback. Concerning the underlying mechanism of the motivating effect of competition, it is assumed that competition increased motivation for training activity by serving as an externally added benefit to the task e.g. by the expectation of winning based on the benefit-cost framework theory. Competition turned out to be a valuable instrument to increase motivation for self-directed training as intensity and number of repetitions of exercises were raised in the required way (see chapter 4.3.1). Consequently, competition should be integrated as a beneficial component to self-directed training in neurorehabilitation.

7.2 Discussion of Secondary Outcomes

7.2.1 The Perceived Exertion

In this study, an additional analysis of subjective effort during a training session was carried out with no a priori predictions. However, analysis helped to identify possible modulating factors to performance. Perceived exertion was examined in relation to the three main predictors: training performance, time and experimental condition.

i) Conception of the Test

The Borg RPE scale has been proven to be an adequate tool in terms of simplicity [163] and test-retest reliability [166, 189] to evaluate individual levels of exertion during performance [17, 162]. The chosen scale from 6-20 is a reliable instrument, especially for subjective ratings of cycling performance [162, 166, 190]. This secondary outcome served as an additional subjective component for the evaluation of training performance. Furthermore, secondary outcome was deemed to help identify potential modulating factors on training activity and to expand knowledge on the underlying mechanism of competition. Moreover, ratings of perceived exertion were used together with the measure increase in heart rate, to guarantee the health-related security of participants. It served as a tool to monitor dangerous overstressing during self-directed training.

ii) Discussion of Method

Participants were asked to rate their training performance in the post-training meeting. For this purpose, a scale with numbers and short, written explanations were added to make it easy to understand the scale (see annex VI). However, this testing method requires the ability to understand written or spoken content. As mentioned before, aphasia is a neuropsychological deficit of the speech which is a common post-stroke feature. In some types of aphasia also the understanding of speech can be impaired. Thus, inclusion criteria of the study were designed to exclude potential participants who had been diagnosed with aphasia. The rating of perceived exertion not only requires the ability to understand written or spoken content but also requires a realistic self-assessment. To guarantee a significant rating, participants need to be instructed precisely on how to use the scale [72]. Participants were trained in using the Borg scale during pre-exercise testing that served as an introduction to the training tool and proceedings. Nevertheless, if considering these restrictions, it is believed that the Borg scale is a valuable tool to reflect individual training performance [72] in this study.

iii) Discussion of Results

Firstly, findings in relation to the first predictor training performance demonstrated that subjective training effort increased with mounting physical load (see Table 4). This finding supports existing knowledge on the positive scaling of perceived exertion and cycling activity [e.g. 190].

Moreover, this analysis of perceived exertion was interesting in relation to the study question dealing with the underlying mechanism of competition. A relationship between the perception of activity and motivational aspects has been reported recently. For instance, a study from 2013 by Fritz et al. presented evidence that physical activity enhanced with music that matched movements of an exercise compared to a control condition [191]. Interestingly, participants reported a lower level of exhaustion after the musically-assisted performance than after the control condition. This was even though the same level of effort was carried out.

This effect may be explained by the benefit-cost framework for consideration of the benefit of an action and its charge [107] as laid out in the introduction (see 4.4.1). If the benefit of an action is assessed to be higher than the benefit of a similar one, likelihood for behavior is increased in favor of the action with the perceived higher benefit. In that sense, music could have served as a benefit to the task as it increased the joy of the activity [31]. Accordingly, perceived exertion of self-directed training in this study would have been expected to be lower, as the benefit of task was raised at the expense of its "charge" through the added extrinsic motivator competition [31].

However, in this sub-question, the GEE model analysis demonstrated mean training performance independently from the type of experimental condition. A lowered perceived exertion could have been expected only during competition terms that presented the extrinsically-controlled benefit. Isolating the effect of competition on perceived exertion of physical effort is thus not possible with this method. The second GEE model did not differentiate between the three conditions. For this reason, it can only be assumed that perceived exertion could have been lower during a competition on the background of the benefit-cost framework [107].

On the other hand, evidence from other disciplines of research like sports science or psychology insists that competition increases the effort put into activities [e.g. 14, 15, 16]. More effort rated on a scale during competition could thus simply represent the objective increase in training performance. Summarizing findings of this study, it is shown firstly that training performance was highest during a competition (see e.g. Fig. 11 A). Secondly, it was found that training performance and subjective physical load are co-varying factors (see Table 4). Following this line of proposition, perceived exertion would have been raised with training performance during competitions. However, concrete testing of effect of competition on perceived exertion is needed to expand the current knowledge.

No significant effect was found with perceived exertion and the second predictor time (see Table 4). Time passed did not affect the subjective training effort rated on the Borg scale. These findings were not encouraging as a kind of training effect could have been expected. According to theories in training therapy in neurorehabilitation (see 4.3.2), fitness levels were expected to improve after endurance training through self-directed training. It was assumed that the required stress level for adapting processes was achieved through competitions. In line with the theory of *shaping* (see discussion of primary outcome), the same level of demand should have been perceived lower. Results underline findings from the first GEE model examining primary outcome that found no increase in training performance over time (see Table 2).

However, it is to say that periods of measurements were short in many cases. On average, participants took part in the study for 9 days and trained at least 5 times. In contrast, in a study that found a positive impact of self-directed training of the upper limb, participants exercised gradually for four weeks [12]. Also, the afore-mentioned study by Studer et al., using a similar study design and setting, proved that training performance was raised over time through self-directed training with the added element of competition [31]. In this study, participants performed during workdays with shorter intervals between measurements and more measurements for each participant in total. Therefore, it can be assumed that an improvement in physical fitness may have simply not become obvious through statistical analyses. This assumption is also supported by results received by the analysis of performance tests that will be discussed further in chapter 7.2.3.

The missing influence of the experimental condition (see Table 4) indicates that perceived exertion was not affected by side effects beyond the effects of interventional condition competition such as nervousness or anxiety. As mentioned before, the second GEE model analysis summarized training performance irrespective of the corresponding experimental condition. As positive scaling of competition and increase in training performance has been proven, only additional modulating factors would have become obvious. This result of analyses might be the most interesting. It serves as additional prove that only the factor competition was responsible for higher performances and no other modulation factors.

iv) Conclusion

In summary, these findings confirm the association between perceived exertion and training performance. Already being used in neurorehabilitation measures, findings support proof that the use of the Borg scale in neurorehabilitation is a reliable tool to monitor and evaluate performance. Questions remain on how the perceived exertion of performance is modulated by competition. For monitoring and management of training intensity in exercise therapy, this knowledge could be helpful to allow more individualized care of patients.

This analysis could not find evidence of a training effect. Perceived exertions of the same level of physical load were not altered over time. However, these results might be due to the methodology of the study as evidence exists that self-directed training improves physical fitness [12]. More importantly, by revealing that no side effects manipulated performance, knowledge of the mechanism of competition was expanded. Beyond the proven effect of competition upon training performance, no modulating factors like anxiety or nervousness were identified.

7.2.2 The Increase in Heart Rate

In this study, heart rate measurements were performed to assess the change in heart rate during exercises by variable %maxHR in relation to the three predictors, training performance, time and experimental condition with no a priori predictions. Analysis helped to identify potential side effects, which was deemed to shed light on the study question on the underlying mechanism of competition. Moreover, monitoring of an increase in heart rate in association with or with measuring measure perceived exertion served as a control instrument of health state of participants during self-directed training.

i) Conception of the Test

As a cause of a stroke, patients are commonly deconditioned (see chapter 4.2.5 and 4.3.2) and training management can thus be challenging. Considering the study question on the underlying mechanisms of competition, investigation was interesting because of the reported relation of heart rates and emotionality. A review examining 134 experimental trials has found that the modification in heart rate is related to the level of excitement during different emotional states [192]. Hence, it has been interesting to test the development of heart rates during the experimental conditions to identify additional modulating factors. Moreover, evidence exists that heart rates correspond with the physical effort of individuals [193]. Although exercise training has been proven to decrease the risk of secondary complications post-stroke (e.g. recurrent strokes or cardiac events), it might also lead to complications [63]. It is therefore essential to monitor heart rates for safety reasons, especially to reduce risks of cardiac events. Potential participants that had been diagnosed with pre-existing cardiac diseases like coronary heart diseases were not included (see chapter 5.1.3 for details). Also, %maxHR measurements were useful to evaluate whether a participant was reaching the therapy effective training intensity (see 4.3.2).

ii) Discussion of Method

Many tools for the management of training therapy in neurorehabilitation are available. To reach and control individual training, effective levels of exercises, specialist literature on physiotherapy recommends the use of pulse detection, measurement of heart rate by chest bands, and the use of the Borg scale [72]. Pulse and heart rate can be calculated by the use of the Karvonen formula as performed in this study. These recommendations are due to evidence that found a linear relation between heart rate and energy consumption [194]. In this study, measurements needed to be integrated in everyday clinical practice and save time and personnel resources. Therefore, the use of elaborated spirometry was rejected. Moreover, the recording of cardiovascular reaction is a compulsory measurement variable for all treadmill- or bicycle-based exercise testing [163].

A possible weakness of this method was due to measurement failures. The training tool and chest bands sometimes did not connect. If the chest band was placed inadequately on the participant by the examiner or slipped during non-supervised exercises, data were not recorded. Thus, many participants were not included into final sample of heart-rate measurements. Some participants felt uncomfortable wearing the chest band and strictly denied it. Thus, data presented in this study were only collected from approximately half of the participants from the final sample.

iii) Discussion of Results

Firstly, results demonstrate non-surprisingly that an increase in heart rate (%maxHR) was significantly associated with training performance (see Table 5). Results fit the existing knowledge on a linear relation between heart rates and oxygen uptake under increasing effort [163, 194]. The higher the participant's effort, the higher the heart rate.

Secondly, %maxHR was not significantly changed by predictor time (see Table 5). Heart rates were not affected by the time passed since beginning of measurements. %maxHR was not altered during the same level of stress over time. This could be regarded as rather contradictory because with an increase in physical performance, a kind of training effect could have been expected. This training effect would have been represented by a lower percentage of %maxHR reached during the same level of physical performance. These findings are in line with findings gained through secondary outcome perceived exertion. Also, perceived exertion was not altered by time passed. What is the reason for these conflicting results?

One possible source of error may be due to small sample size (see 5.1.3). In contrast to the secondary outcome of perceived exertions, measurements were included from only approximately half of the participants from the final sample. Also, time intervals of measurements were big. Exercises in this study only took place on the weekends with an interval of 5 days in between. Additionally, the period of participation was short for many participants who had a minimum of 5 training sessions and a total period of participation of at least 9 days. This assumption is supported by findings from the afore-mentioned study by Harris [12], who proved beneficial effects of self-directed training. In this study, the period of measurements consisted of four weeks. Also, results of performance tests that are discussed in the following assume that participants improved their cardio-respiratory fitness. Therapy-effective training intensity is reached at a percentage of 50-80 % of maximum heart rate [63] (see 4.3.2). The mean percentage of maximum heart rate was 57%. Thus, results of this study indicate that participants were exercising at the required intensity to achieve improvements in fitness. Hence, data of this analysis must be interpreted with caution as effect may simply not become obvious through statistical analyses.

Thirdly, also no association of %maxHR and predictor experimental condition was found (see Table 5). The missing impact of the predictor experimental condition suggests that no additional side effects like nervousness were affecting the percentage of maximum heart rates during exercises. In this sub-question, again, the GEE model analyzed mean training performance independently from the type of experimental condition. Therefore, only side effects like nervousness or anxiety beyond the association between increase in heart rate and training performance would have become obvious. Isolating the effect of competition on increase in heart during physical effort is thus not possible with this method. For this reason, it can only be assumed that heart rate increased during a competition as it has been proven that training performance rose by this factor. Training performance itself co-varied with heart rate in this study. However, the more significant finding from this test demonstrates that training performance was raised exclusively by the factor competition and no other modulating factors were identified. Physical activity was not altered by emotional states.

Lastly, concerning the aim to guarantee the health-related security and management of training intensity through heart rate measurement, results showed the following: the highest reached increase in heart rate was 85% of maximum heart rate and was thus within recommendations. This suggests that participants did not experience a dangerous overstressing by overstepping the recommended level of stress. It is assumed that steps taken to guarantee health-related security (e.g. use of safety cut-off and pre-exercise testing) during self-directed training were successful. Yet, the lowest reached percentage was below recommendations at 36%. This outlier could represent the part of participants that were not reached by the motivating effect of competition and the basic problem with the poor implementation of regular self-directed training (see 4.3.4).

iv) Conclusion

The findings of the present analysis complement and support those of earlier studies. Also in this study, training performance during self-directed training in neurorehabilitation patients correlated with heart rate. Assumably being limited to methodology, no modification in heart rate was found over time. It is probable that security measures taken, like the use of a safety cut-off, were successful and no dangerous overstressing during competitions occurred. Concerning the question on the underlying processes of competition, the most important finding to emerge was that no additional side effects were found. No factors were identified to modulate training activity beyond the proven effect of competition upon training performance. Thus, together with results from the examination of subjective training effort, self-directed training was exclusively raised by the factor competition and was not manipulated by additional effects caused, for instance, by nervousness or anxiety.

7.2.3 Performance Tests

Two performance tests, a pre- and a post-performance test, were used in this study. By comparison of the two tests, changes in exercise tolerance through self-directed training were evaluated. Self-directed training was expected to increase physical fitness. After the test both the participant and the examiner rated the effort of the participant during the performance tests by the use of the Borg scale. A comparison between perceived exertion of participants and the evaluation of exertion by the examiner were made without specific predictions.

i) Conception of Test

Performance tests in this study were conducted for two reasons. The first reason was to reduce the health risks of participants during self-directed training. In accordance with the AHA, it is recommended to perform graded exercise testing to evaluate individual states of health and the trainability of participants prior to exercises [63]. Two performance tests for each participant were conducted. The pre-performance test was important to identify possible health risks. A strong relationship between pre-exercise graded performance tests as recommended by the AHA [see 63] and the reduced risk of cardio-vascular complication has been reported in literature [195]. Risks for post-stroke complications through self-directed training are thus assumed to be lowered to a satisfactory level [63]. Similar tests are also being performed prior to exercise training in neurorehabilitation. The test also helped to introduce participants to the training tool, study proceedings and to evaluate individual performance levels afterwards.

Secondly, performance tests served as an evaluation tool for objective improvements in fitness through self-directed training. Through comparison between pre-and post-performance test, an analysis of individual changes in performance capability was possible. Categorization of results was made by three groups, defined as “improvement”, “worsening” and “no change” of physical fitness. It was possible to “improve” fitness by reaching a lower pulse on the same level of intensity or by reaching a higher step of intensity.

WCBTs are cycling tools that allow physical training even with low strength and endurance through motor support. Some participants of the sample had little strength in the lower limb due to post-stroke impairments or deconditioning (see 4.2.5). As steps of intensity in the performance test were broad, reaching a higher step might have been too difficult for some participants (as also performance spectrum was broad in the sample). This concern is applied especially when concerning the short period of exercise. Thus to receive conclusive results, a second way of improving was introduced to the category.

ii) Discussion of Method

The main weakness of this method is that performance tests are only brief snapshots of performance. Results of performance tests are dependent on the daily condition of the participant. Daily condition could have been affected by the general medical state, the psychological condition or the grade of physical exhaustion of the addressed person. Due to regular rehabilitation measures that had been received on the day of measurement, participants might have been exhausted. Performance tests were conducted prior to self-directed training during the week usually after regular rehabilitation routines. Some measures may have been more demanding than others. Thus, it is possible that participants performed worse or better on one day than they would have performed on another day.

Also, as performance tests are designed to test out capability limits, a certain level of motivation and engagement in the activity is required. If participants were unmotivated, performance tests would not reflect the level of physical performance properly. Therefore, the Borg scale was used to evaluate the subjective level of stress reached during testing period. For example, if a performance test was perceived to have been easy by the participant, it can be assumed that the test was not a proper reflection of performance capability. However, due to the reliability of the Borg scale [194] and as most participants rated exertion as very high (see 6.2.3), it is assumed that performance tests were successful.

However, results of analyses of the performance test must be interpreted with caution in general due to the small sample size of analyzed performance tests as less than the half of participants performed both pre- and post-performance tests. It is to note that participants received regular neurorehabilitation measures that are designed to improve endurance and strength (see 4.3.2). Moreover, with no control group that only received regular rehabilitation measures and no additional self-directed training being tested, caution must be applied. In contrast, a study by Duncan from 2003 tested the evidence of training effect through a home-based exercise program [196]. In this study, two groups of out-patient stroke survivors receiving subacute stroke-care were tested. One group received regular rehabilitation measures and one interventional group performed additional therapist-supervised, home-based training. The interventional group improved physical parameters to a greater extent in comparison to the control group [12].

iii) Discussion of Results

Results gained through comparison between pre- and post-performance test showed an improvement in training performance with most participants, as presented in Fig. 12. By this result, it can be assumed that most participants improved their physical fitness through self-directed endurance training in the context of this study.

Equal shares of samples improved their physical fitness by reaching higher Watts (see Table 6) and by reaching a lower pulse while having reached the same intensity in the post-performance test as in the pre-performance test. A possible explanation for the first result is that participants experienced an increase in muscle strength through regular exercising in training sessions. Thus, they could cope with higher intensity. An observed decrease in heart rate while performing on the same step of intensity as in the pre-performance test may be the result of higher cardiopulmonary persistence, gained through aerobic training. Cardiopulmonary endurance training on an aerobic level actively influences muscle strength, persistence and the blood pressure in a positive way [63]. It is probable that a lower heart rate represents lower exertion during the same effort (comparing pre- with post-performance test).

Though, again, results need to be interpreted with caution as the period of participation was short (on average 9 days), and it is questionable if an adaption of muscles occurred already. Moreover, no measurement of actual muscle growth, for example by measurement of calf circumference, was performed in this study. However, aerobic endurance training is known to have several instant effects such as an increase in blood circulation, neural adaption and prevention of muscle atrophy (see 3.3.3.),that can be achieved already during an exercise after only few seconds to minutes [79]. It is thus postulated that self-directed training in fact had a positive influence on the physical fitness of participants in this study. Moreover, performances were not hampered by co-existing risk factors in the sample, which could be interpreted as additional proof of the good trainability of stroke patients as suggested by the AHA [63].

Most participants performed the tests abiding by the rules consistently in the pre-performance test. This means that the test was completed (fully to the highest step of intensity) or heart rates were too high to continue the test safely. This might show that participants exercised at their capability limits and the test was thus successful. However, the post-performance test showed a greater share of early stops of testing, which was somehow surprising. In this line, also 33.3 % of participants “worsened” their fitness level according to the overall assessment. This could be a result of loss in motivation to complete the exhausting test a second time. Other than self-directed training, the performance test was designed to test out capability limits and is therefore exhausting. Also, motivating elements like feedback or self-determination aspects were missing. For this reason, it is surprising that the performance test was more vulnerable to a motivation loss than self-directed training.

However although it cannot be excluded that this happened with some participants, it is assumed that most performance tests were meaningful, as total assessment showed an improvement in performance in 60% of the participants. Also, findings from the study by Studer et al. (2016) that used a similar study design demonstrated a training effect through self-directed training [31]. Thus, these observations may support the hypothesis that participants improved their cardio-respiratory fitness through self-directed training.

Analysis of perceived exertion (Borg scale) of performance tests demonstrated that the valuation of exertion by both the participant and the examiner were correlating (see Fig. 13). Although participants evaluated performance as slightly more strenuous than the examiner (see 6.2.3), a significant correlation was found. This result was rather surprising. Due to deconditioning and functional disabilities, post-stroke exercise tolerance is reduced [62] (see chapter 4.2.5 and 4.3.2.). Several lines of evidence confirmed the higher energy demand in hemiplegic patients, for example by means of heightened oxygen admission during gait compared to weight-matched healthy people [58, 59]. It has thus been assumed that it would be difficult for external persons to assess the effort of participants. However, results of the present study indicate that the level of exhaustion of participants was well estimated by the examiner. Hence, it is assumed that the management of exercise training and of pre-exercise testing in this study was successful. In Fig. 13 it seems like the correlation became even stronger in the post-performance test. This instant may be due to the increased experience in use of the Borg scale in the post-performance test. As mentioned before, the correct use of the Borg scale needs to be practiced [72].

iv) Conclusion

This combination of findings provides some support to previous studies that found beneficial effects of self-directed training. By comparison of pre-and post-performance test, it is believed that participants improved their physical fitness in this study. Moreover, findings helped to broaden the understanding of self-directed training. Previous research examined self-directed training of the upper limb. This study contributes to knowledge, provided by Studer et al. [31] that found beneficial effect of self-directed training on WCBT of the lower limb. Lastly, findings indicate that effort of participants was reliably assessed by the examiner. It is thus assumed that exercise management and management of pre-exercise testing in terms of health-related security were successful.

7.3 Possible Limitations to the Potential of Competition

Beside the positive outcomes during competition in the present study, it is crucial to note that not all participants might have been affected in the same positive way. This might be the result of the aforementioned individual and state-dependent differences in responsiveness to competition [107]. In this context, literature supporting arguments against the application of competition need to be debated.

The first main argument against the insertion of competition claims that it could affect performance outcomes negatively as the result of increased pressure and anxiety [14, 134, 197]. DiMenichi, for instance, proved on the one hand that reaction times were faster during competition. On the other hand, he presented data which showed that during direct confrontation with an opponent, outcome decreased. Similarly, Cooke (2011) discovered that although performance increased through competition, self-reported anxiety was enhanced. An explanation for these observations could be provided by the benefit-cost-framework theory [107]. Costs of exercise (e.g. fear of injury or fear of social decent [147, 156]) might have exceeded its benefits (outperforming an opponent, joy of winning) [31].

Another argument was stated by Deci [123, 176] in regard to the self-determination theory [110]. He proposed that extrinsic motivators (like in this case competition) can in some ways impact inner motivation negatively and therefore lead to a reduction of performance and achievements [123, 176]. Following these arguments, it can be said that using competition in neurorehabilitation measures would be more of a risk than a benefit. It might result in contrary effect and worsen the participant's rehabilitation prognosis.

However, taking these arguments seriously, this doctoral thesis argues that competition can be a useful tool to boost motivation with the restriction that it must follow accurate control of frame conditions. Certainly, a growth of pressure and anxiety [14, 134, 197] is an undesired effect, especially among stroke patients who have little stress tolerance [76] and sometimes also suffer from a form of post-stroke depression [198]. However, it can be assumed that this effect was less pronounced in this study, as a strongly significant result of the increase in physical performance attests. In the majority of participants, a boost of training performance rather than a restriction occurred, which would have been the case with increased anxiety and pressure [14, 134, 197] and undermined intrinsic motivation [123, 176]. Also, no uncontrolled factors were found by analyses of secondary outcomes (see 7.2.1, 7.2.2), indicating that only competition influenced performance, and no other modulating factors. However, as no direct scientific evidence was collected on the perceived anxiety and pressure, it can only be assumed that this effect did not occur.

Considering the argument by Deci [123, 176], this dissertation argues that competition, as an extrinsic motivator, did not influence the inner motivation notably. By reviewing the afore-said literature, it has been found that reported weakened performance was mostly driven by intrinsic forces that were deemed to enhance for instance the joy of the relative activity [31]. In contrast, motivation in this study is assumed to have been mostly driven by extrinsic goals (e.g. improvement of mobility, endurance, persistence and general well-being). Therefore, it can be presumed that this concern is not applied in this case.

To create appropriate frame conditions for competition, additional measures based on scientific evidence on the increase of motivation were taken as demonstrated in chapter 1.15. It was ensured by the cover-story that participants felt self-determent [111, 124, 159-161], that they had the impression to have a realistic chance of winning, as well as to receive an external reward (in this case winning a competition or receiving feedback). Beyond that, additional rules were created to avoid the appearance of negative emotions. Avoidance of side effects like anxiety or nervousness and therefore ensuring the isolated examination of competition were maintained through the high-level control condition feedback [111]. By keeping the competition anonymous at all times, it was ensured that participants did not have to fear a decline in social status [147, 156], and were able to avoid anxiety and pressure [14, 134, 197]. Given the theory of competition being situation related [124, 159], the atmosphere during exercises was designed to be easy as there were no consequences following a competition (e.g. no prize if somebody won or punishment if somebody lost). This situation was designed in the style of a previous study that was carried out as an academic tournament by van Nuland (2015) and Burguillo (2010). The tournament was described as "not too serious" to prevent anxiety and pressure. They proved that this way competition increased academic performance [14, 134, 197].

To summarize, the present study proved that if setting explicit rules and if monitoring is possible, competition, as an externally added benefit, could be a reliable tool. This way, motivation for exercises of patients undergoing neurorehabilitation measures to increase number of repetitions and intensity can be enhanced.

7.4 Advice for future Research

This study was a first approach to test effects of competition in the healthcare scope of application. Future research could deal with finding ways to integrate this knowledge into the clinical practice of neurorehabilitation measures. Building on this study, also other possibilities of using the factor competition in neurorehabilitation should be examined in the future, for example, the use of competition by examining other training therapies and tools, e.g. treadmills.

Also, it would be interesting to expand knowledge on individual differences in responsiveness to competition [31]. Motivation can not only be classified as internally or externally driven but is also assumed to be subject of individual differences in behavior to the same motive [107, 118, 199-201]. Several studies mentioned individual differences between different characters [202-204], but also generally between males and females during competition [e.g. 205]. This is congruent with evidence that identified the sex hormone testosterone to be responsible for a willingness to fight, a rise in social status [147] and the responsiveness to competitions [150-152]. It has been proven that testosterone is secreted and represented differently in males and females [149]. The question as to whom exactly competition could be a beneficial tool in neurorehabilitation is of major interest.

The present study was not determined to identify an individually different responsiveness to competition but to be a first approach to prove its effect on patients in general. Building upon this, a detailed gender-specifically examination of the influence of competition on training performance, for instance by the use of the GEE model could be an interesting approach. This scientific knowledge could allow a more personalized approach towards a patient's needs in neurorehabilitation.

Another possible area of research would be to assess different types of competition to find the most motivating one [31]. In this study, single competitions with a participant having one opponent were conducted. Tauer and Harackiewicz (2004) examined, for example, motivating effects of competitions between teams. They found that competition in combination with cooperation aspects led to higher motivation [154].

Deeper investigations of the clinical potential of competition would integrate research on the biochemical level [31]. Neuroscience has a great potential to complement subjective measures (like self-reports) from psychological research with objective ones [206]. Despite the promising results of research on the biochemical process of the rewarding system [137-142], questions remain. A first approach by investigating the role of testosterone as a biochemical signal of "winning" was taken [122, 145, 146]. This scientific knowledge could be used to investigate clinical applications. This could be an approach to find ways to manipulate biochemical processes by drug administration to increase motivation. For this purpose, messenger substance testosterone [e.g. 122] or also other neuroactive neuroendocrinological substances which were found to modulate human behavior [119] could be investigated.

Summarizing this, many issues concerning basic research on factor competition have been clarified so far. However, many questions in the medical field dealing with the factor competition and its application in clinical practice remain unanswered and are in need of further investigation.

7.5 Conclusion

A stroke is the severest neurological disorder, causing disabilities to the highest extent [1]. Treatment of a stroke and management of this neurological disorder is the most cost-intensive discipline in medicine [23]. Given the importance of improving the management of impairments after a stroke, self-directed training is a meaningful instrument for neurorehabilitation.

This additional rehabilitation measure increases the crucial factors for utilizing a patient's full rehabilitation potential: frequency and intensity of physical endurance training [2, 3, 5-7]. Self-directed training can bridge the gap between the required treatment time and effort in neurorehabilitation and scarce resources. Yet, decreasing or lacking motivation is the most frequent reason why this effective neurorehabilitation measure often fails [13, 21]. Based on evidence found on performance-enhancing effects of competition from diverse fields of research, the study project intended to examine adding the factor competition to self-directed training. Research questions were firstly whether competition is a sufficient tool to increase self-directed training. Secondly, the issue was to analyze how strong this effect would be. Thirdly, the aim was to clarify the underlying mechanism of increasing motivation through competition.

In this proof-of-concept study, participants were in-patient stroke patients undergoing neurorehabilitation. Each participant undertook self-directed training as cardio-respiratory endurance training on a wheelchair-compatible bicycle trainer (WCBT). Training activity was recorded under three experimental conditions, two control conditions (baseline and feedback), and one interventional condition, the competition condition, repeatedly. Training performance served as a primary outcome that was compared within conditions. It was hypothesized that training performance will be raised through the added element competition. Two secondary outcomes, the increase in heart rate (%maxHR) and the perceived exertion of training sessions were measured in addition and with no a priori predictions. Performance tests took place prior to the first and after the last training session to evaluate the objective change in physical fitness through self-directed training.

The result demonstrated that primary outcome training performance was highest during the intervention condition competition. Participants performed self-directed training significantly longer and more intensively during a competition situation. Feedback and baseline, on the other hand, were not found to improve motivation. Beyond this association, no additional modulating effects like anxiety or nervousness were found to alter performances. Most participants experienced an improvement in cardio-respiratory fitness through self-directed training in this study. Unfortunately, besides promising results of performance tests, no improvement of fitness was found by analyses of secondary outcomes (increase in heart rate and perceived exertion). It is assumed that conflicting results are due to the methodology and setting of the study.

The effect of competition was strongly significant. It is proposed that competition is a more powerful instrument to enhance performance than giving feedback. As an underlying mechanism, increased motivation by the added factor competition was identified. Considering the benefit-cost-framework theory [107], competition might have served as an additional extrinsic motivator that increased the benefit of self-directed training by the expectation of the chance to win. This might have outweighed the theoretical costs of exercising [31]. By setting explicit rules and creating ideal basic conditions through full experimental control, it is assumed that negative emotions like anxiety that could undermine motivation did not play a role [31].

This thesis was a first approach to test the potency of competition on motivation for physical tasks in neurorehabilitation with stroke patients rather than with physically fit participants. Based on significant scientific evidence, this dissertation claims that competition could be an adequate and effective instrument for promoting self-directed training in neurorehabilitation. By inserting competition to self-directed training, intensity and duration of exercises can be improved and patients are able to utilize their full rehabilitation potential. This way, self-directed training could bridge the gap between required intensity of exercise therapy and neurorehabilitation resources. This would improve the perspective of stroke patients by increasing health, physical fitness and the participation in activities of daily life.

8. References

1. Mukherjee, D. and C.G. Patil, *Epidemiology and the Global Burden of Stroke.* World Neurosurgery, 2011. **76**(6): p. S85-S90.
2. Knecht, S., et al., *Old benefit as much as young patients with stroke from high-intensity neurorehabilitation: cohort analysis.* Journal of Neurology Neurosurgery and Psychiatry, 2016. **87**(5): p. 526-530.
3. Albert, S. and J. Kesselring, *Neurorehabilitation of stroke.* Journal of Neurology, 2012. **259**(5): p. 817-832.
4. Krakauer, J.W., et al., *Getting neurorehabilitation right: What can be learned from animal models?* Neurorehabilitation and Neural Repair, 2012. **26**(8): p. 923-931.
5. Zeiler, S.R. and J.W. Krakauer, *The interaction between training and plasticity in the poststroke brain.* Current Opinion in Neurology, 2013. **26**(6): p. 609-616.
6. Kleim, J.A. and T.A. Jones, *Principles of experience-dependent neural plasticity: Implications for rehabilitation after brain damage.* Journal of Speech Language and Hearing Research, 2008. **51**(1): p. S225-S239.
7. Taub, E., et al., *Technique to Improve Chronic Motor Deficit after Stroke.* Archives of Physical Medicine and Rehabilitation, 1993. **74**(4): p. 347-354.
8. Lang, C.E., J.R. MacDonald, and C. Gnip, *Counting Repetitions: an Observational Study of Outpatient Therapy for People with Hemiparesis Post-Stroke.* J Neurol Phys Ther, 2007. **31**(1): p. 3-10.
9. Kaur, G., C. English, and S. Hillier, *How physically active are people with stroke in physiotherapy sessions aimed at improving motor function? A systematic review.* Stroke Res Treat, 2012. **2012**: p. 820673.
10. Bernhardt, J., et al., *Little therapy, little physical activity: rehabilitation within the first 14 days of organized stroke unit care.* J Rehabil Med, 2007. **39**(1): p. 43-8.
11. Fertl, E., *Grundlagen der neurologischen Rehabilitation*. Klinische Neuropsychologie: Grundlagen—Diagnostik—Rehabilitation, ed. P.G. Lehrner J., Fertl E., Kryspin-Exner I., Strubreither W. 2006, Vienna: Springer. 529-541.
12. Harris, J.E., et al., *A Self-Administered Graded Repetitive Arm Supplementary Program (GRASP) Improves Arm Function During Inpatient Stroke Rehabilitation A Multi-Site Randomized Controlled Trial.* Stroke, 2009. **40**(6): p. 2123-2128.
13. Tyson, S., et al., *Phase II Pragmatic Randomized Controlled Trial of Patient-Led Therapies (Mirror Therapy and Lower-Limb Exercises) During Inpatient Stroke Rehabilitation.* Neurorehabil Neural Repair, 2015. **29**(9): p. 818-26.
14. Cooke, A., et al., *Effects of competition on endurance performance and the underlying psychological and physiological mechanisms.* Biological Psychology, 2011. **86**(3): p. 370-378.
15. Triplett, N., *The dynamogenic factors in pacemaking and competition.* The American journal of psychology, 1898. **9**(4): p. 507-533.
16. Brown, S.P., W.L. Cron, and J.W. Slocum Jr, *Effects of trait competitiveness and perceived intraorganizational competition on salesperson goal setting and performance.* The Journal of Marketing, 1998: p. 88-98.
17. Borg, G.A., *Psychophysical bases of perceived exertion.* Med sci sports exerc, 1982. **14**(5): p. 377-381.
18. Cooper, D.J. and H. Fang, *Understanding overbidding in second price auctions: An experimental study.* Economic Journal, 2008. **118**(532): p. 1572-1595.

19. Roider, A. and P.W. Schmitz, *Auctions with Anticipated Emotions: Overbidding, Underbidding, and Optimal Reserve Prices.* Scandinavian Journal of Economics, 2012. **114**(3): p. 808-830.

20. Grimm, V. and D. Engelmann, *Overbidding in first price private value auctions revisited: implications of a multi-unit auctions experiment*, in *Advances in Public Economics: Utility, Choice and Welfare*. 2005, Springer. p. 235-254.

21. Horne, M., et al., *Patient-directed therapy during in-patient stroke rehabilitation: stroke survivors' views of feasibility and acceptability.* Disabil Rehabil, 2015. **37**(25): p. 2344-9.

22. Lozano, R., et al., *Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010.* Lancet, 2012. **380**(9859): p. 2095-2128.

23. Murray, C.J., et al., *Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010.* Lancet, 2012. **380**(9859): p. 2197-223.

24. Aho, K., et al., *Cerebrovascular-Disease in the Community - Results of a Who Collaborative Study.* Bulletin of the World Health Organization, 1980. **58**(1): p. 113-130.

25. Sin, M.A., et al., *Gesundheit in Deutschland. Gesundheitsberichterstattung des Bundes.*, R. Koch-Intitut, Editor. 2015, Robert Koch-Institut: Berlin. p. 43-49.

26. Writing Group, M., et al., *Heart disease and stroke statistics-2016 update: A report from the American Heart Association.* Circulation, 2016. **133**(4): p. e38-360.

27. Hacke, W., et al., *Recommendations of the European Stroke Initiative for management and treatment of stroke.* Nervenarzt, 2001. **72**(10): p. 807-819.

28. Freimuller, M. and K. Fheodoroff, *Neurorehabilitation after stroke.* Wien Med Wochenschr, 2003. **153**(1-2): p. 25-8.

29. Prabhakaran, S., et al., *Inter-individual variability in the capacity for motor recovery after ischemic stroke.* Neurorehabil Neural Repair, 2008. **22**(1): p. 64-71.

30. Duncan, P.W., et al., *Measurement of motor recovery after stroke. Outcome assessment and sample size requirements.* Stroke, 1992. **23**(8): p. 1084-9.

31. Studer, B., et al., *Increasing self-directed training in neurorehabilitation patients through competition.* Progress in Brain Research, 2016.

32. Lang, C.E., et al., *Observation of Amounts of Movement Practice Provided During Stroke Rehabilitation.* Archives of Physical Medicine and Rehabilitation, 2009. **90**(10): p. 1692-1698.

33. Nicholson, S., et al., *A systematic review of perceived barriers and motivators to physical activity after stroke.* Int J Stroke, 2013. **8**(5): p. 357-64.

34. Strong, K., C. Mathers, and R. Bonita, *Preventing stroke: saving lives around the world.* Lancet Neurology, 2007. **6**(2): p. 182-187.

35. Feigin, V.L., et al., *Worldwide Stroke Incidence and Early Case Fatality Reported in 56 Population-based Studies: a Systematic Review.* Lancet Neurology, 2009. **8**(4): p. 355-369.

36. Sudlow, C. and C. Warlow, *Comparing stroke incidence worldwide.* Stroke, 1996. **27**(3): p. 550-558.

37. Kolominsky-Rabas, P.L., et al., *A prospective community-based study of stroke in Germany—the Erlangen Stroke Project (ESPRO) incidence and case fatality at 1, 3, and 12 months.* Stroke, 1998. **29**(12): p. 2501-2506.

38. Feigin, V.L., et al., *Global and regional burden of stroke during 1990-2010: findings from the Global Burden of Disease Study 2010.* Lancet, 2014. **383**(9913): p. 245-54.

39. Krishnamurthi, R.V., et al., *Global and regional burden of first-ever ischaemic and haemorrhagic stroke during 1990-2010: findings from the Global Burden of Disease Study 2010.* Lancet Glob Health, 2013. **1**(5): p. e259-81.

40. Foerch, C., et al., *The projected burden of stroke in the German federal state of Hesse up to the year 2050.* Dtsch Arztebl Int, 2008. **105**(26): p. 467-73.

41. Truelsen, T., et al., *Stroke incidence and prevalence in Europe: a review of available data.* Eur J Neurol, 2006. **13**(6): p. 581-98.

42. Heuschmann, P.U., et al., *Ethnic group disparities in 10-year trends in stroke incidence and vascular risk factors the South London Stroke Register (SLSR).* Stroke, 2008. **39**(8): p. 2204-2210.

43. Kavanagh, S., M. Knapp, and A. Patel, *Costs and disability among stroke patients.* Journal of Public Health Medicine, 1999. **21**(4): p. 385-394.

44. Günster, C., J. Klose, and N. Schmacke, *Versorgungsreport 2011 Schwerpunkt: Chronische Erkrankungen*, in *Versorgungsreport*. 2010: Stuttgart. p. 372.

45. Kolominsky-Rabas, P.L., et al., *Lifetime Cost of Ischemic Stroke in Germany: Results and National Projections from a Population-based Stroke Registry - The Erlangen Stroke Project.* Stroke, 2006. **37**(5): p. 1179-1183.

46. Kolominsky-Rabas, P.L. and P.U. Heuschmann, *Incidence, etiology and long-term prognosis of stroke.* Fortschritte Der Neurologie Psychiatrie, 2002. **70**(12): p. 657-662.

47. Ward, A., et al., *Care needs and economic consequences after acute ischemic stroke: the Erlangen Stroke Project.* European Journal of Neurology, 2005. **12**(4): p. 264-267.

48. Schneider, K., et al., *Situation of life and care in patients with a stroke.* Nervenheilkunde, 2009. **28**(3): p. 114-+.

49. Günster, C., *Schlaganfallversorgung in Deutschland–Inzidenz, Wiederaufnahmen, Mortalität und Pflegerisiko im Spiegel von Routinedaten.* Versorgungsreport, 2011. **147**.

50. Hacke, W. and K. Poeck, *Neurologie*. Vol. 13.Auflage. 2010, Heidelberg: Springer Medizin Verlag. 844.

51. Van der Worp, H.B. and J. van Gijn, *Acute ischemic stroke.* New England Journal of Medicine, 2007. **357**(6): p. 572-579.

52. Qureshi, A.I., et al., *Spontaneous intracerebral hemorrhage.* N Engl J Med, 2001. **344**(19): p. 1450-60.

53. D'Souza, S., *Aneurysmal Subarachnoid Hemorrhage.* J Neurosurg Anesthesiol, 2015. **27**(3): p. 222-40.

54. Bender, A., *Kurzlehrbuch Neurologie*. Vol. 2. Auflage. 2015, Urban & Fischer München: Elsevier GmbH.

55. World Health Organization, *International Classification of Functioning, Disability and Health: ICF*. 2001: World Health Organization.

56. Schubert, M.F., *Schlaganfall*, in *Klinische Neuropsychologie*. 2011, Springer. p. 345-356.

57. Sommerfeld, D.K., et al., *Spasticity after stroke its occurrence and association with motor impairments and activity limitations.* Stroke, 2004. **35**(1): p. 134-139.

58. Waters, R.L. and S. Mulroy, *The energy expenditure of normal and pathologic gait.* Gait & posture, 1999. **9**(3): p. 207-231.

59. Olney, S.J., et al., *Work and power in gait of stroke patients.* Archives of physical medicine and rehabilitation, 1991. **72**(5): p. 309-314.

60. Hackett, M.L., et al., *Frequency of depression after stroke a systematic review of observational studies.* Stroke, 2005. **36**(6): p. 1330-1340.

61. Paolucci, S., et al., *Post-stroke depression, antidepressant treatment and rehabilitation results.* Cerebrovascular diseases, 2001. **12**(3): p. 264-271.

62. Ivey, F., et al., *Cardiovascular health and fitness after stroke.* Topics in stroke rehabilitation, 2005. **12**(1): p. 1-16.

63. Gordon, N.F., et al., *Physical activity and exercise recommendations for stroke survivors: an American Heart Association scientific statement from the Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention; the Council on Cardiovascular Nursing; the Council on Nutrition, Physical Activity, and Metabolism; and the Stroke Council.* Circulation, 2004. **109**(16): p. 2031-41.

64. Wallesch, C.-W., *Integrated Stroke Care.* Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz, 2015. **58**(4): p. 393-397.

65. Langhorne, P., et al., *Do Stroke Units Save Lives?* The Lancet, 1993. **342**(8868): p. 395-398.

66. Heuschmann, P.U., et al., *Frequency and Care of Stroke in Germany.* Aktuelle Neurologie, 2010. **37**(7): p. 333-340.

67. Bundesarbeitsgemeinschaft für Rehabilitation, *Empfehlungen zur Neurologischen Rehabilitation von Patienten mit schweren und schwersten Hirnschädigungen in den Phasen B und C*, in *BAR Publikation, Frankfurt/Main*. 1999.

68. Bobath, B., et al., *Abnorme Haltungsreflexe bei Gehirnschäden: 35 Abbildungen*. 1976: G. Thieme.

69. Nudo, R.J., *Functional and structural plasticity in motor cortex: implications for stroke recovery.* Physical Medicine and Rehabilitation Clinics, 2003. **14**(1): p. S57-S76.

70. Blake, D.T., et al., *Experience-dependent adult cortical plasticity requires cognitive association between sensation and reward.* Neuron, 2006. **52**(2): p. 371-381.

71. Bayona, N.A., et al., *The role of task-specific training in rehabilitation therapies.* Topics in stroke rehabilitation, 2005. **12**(3): p. 58-65.

72. Ada, L., et al., *Neuroreha nach Schlaganfall*, ed. J. Mehrholz. 2011: Georg Thieme Verlag.

73. Mackay-Lyons, M.J. and L. Makrides, *Exercise capacity early after stroke.* Arch Phys Med Rehabil, 2002. **83**(12): p. 1697-702.

74. Roth, E.J., *Heart disease in patients with stroke: incidence, impact, and implications for rehabilitation part 1: classification and prevalence.* Archives of physical medicine and rehabilitation, 1993. **74**: p. 752-752.

75. Roth, E.J., *Heart disease in patients with stroke. Part II: Impact and implications for rehabilitation.* Arch Phys Med Rehabil, 1994. **75**(1): p. 94-101.

76. Ivey, F.M., et al., *Cardiovascular health and fitness after stroke.* Top Stroke Rehabil, 2005. **12**(1): p. 1-16.

77. Franklin, B.A. and W. Sanders, *Reducing the risk of heart disease and stroke.* The Physician and sportsmedicine, 2000. **28**(10): p. 19-26.

78. McArdle, W.D., F.I. Katch, and V.L. Katch, *Exercise physiology: energy, nutrition, and human performance.* Medicine & Science in Sports & Exercise, 1991. **23**(12): p. 1403.

79. Berg, F.v.d., et al., *Angewandte Physiologie*. Therapie, Training, Tests. Vol. 3. 2001, Georg Thieme Verlag, Stuttgart, New York: Frans van den Berg. 623.

80. Woldag, H., et al., *Is the repetitive training of complex hand and arm movements benefi cial for motor recovery in stroke patients?* Clinical Rehabilitation, 2003. **17**(7): p. 723-730.

81. Duncan, P., et al., *A Randomized, Controlled Pilot Study of a Home-based Exercise Program for Individuals with Mild and Moderate Stroke.* Stroke, 1998. **29**(10): p. 2055-2060.

82. Eich, H., et al., *Aerobic treadmill plus Bobath walking training improves walking in subacute stroke: a randomized controlled trial.* Clinical rehabilitation, 2004. **18**(6): p. 640-651.

83. Hesse, S., et al., *Treadmill training with partial body weight support compared with physiotherapy in nonambulatory hemiparetic patients.* Stroke, 1995. **26**(6): p. 976-981.

84. Hesse, S., et al., *Body weight-supported treadmill training after stroke.* Curr Atheroscler Rep, 2001. **3**(4): p. 287-94.

85. Macko, R.F., et al., *Treadmill aerobic exercise training reduces the energy expenditure and cardiovascular demands of hemiparetic gait in chronic stroke patients.* Stroke, 1997. **28**(2): p. 326-330.

86. Silver, K.H., et al., *Effects of aerobic treadmill training on gait velocity, cadence, and gait symmetry in chronic hemiparetic stroke: a preliminary report.* Neurorehabilitation and neural repair, 2000. **14**(1): p. 65-71.

87. Macko, R.F., et al., *Treadmill training improves fitness reserve in chronic stroke patients.* Archives of physical medicine and rehabilitation, 2001. **82**(7): p. 879-884.

88. Kamps, A. and K. Schule, *Zyklisches Bewegungstraining der unteren Extremitaten in der Schlaganfallrehabilitation.* NEUROLOGIE UND REHABILITATION, 2005. **11**(5): p. 259.

89. Bocker, B., C. Dietze, and U. Smolenski, *Einfluss von Konditionstraining auf pulmonale Parameter bei Patienten mit Postpoliosyndrom (PPS).* Physikalische Medizin, Rehabilitationsmedizin, Kurortmedizin, 2003. **13**(05): p. 283-285.

90. Brinkmann, J. and T. Hoskins, *Physical conditioning and altered self-concept in rehabilitated hemipelegic patients.* Physical therapy, 1979. **59**(7): p. 859-865.

91. Lohse, K.R., C.E. Lang, and L.A. Boyd, *Is More Better? Using Metadata to Explore Dose-Response Relationships in Stroke Rehabilitation.* Stroke, 2014. **45**(7): p. 2053-2058.

92. Luker, J., et al., *Stroke Survivors' Experiences of Physical Rehabilitation: A Systematic Review of Qualitative Studies.* Arch Phys Med Rehabil, 2015. **96**(9): p. 1698-708.e10.

93. Strombach, T., et al., *Common and distinctive approaches to motivation in different disciplines.* Progress in Brain Research, 2016. **229**: p. 3-23.

94. Gneezy, U., S. Meier, and P. Rey-Biel, *When and why incentives (don't) work to modify behavior.* The Journal of Economic Perspectives, 2011. **25**(4): p. 191-209.

95. Heckhausen, J. and H. Heckhausen, *Motivation und Handeln: Einführung und Überblick*, in *Motivation und Handeln*. 2006, Springer. p. 1-9.

96. Skinner Burrhus, F., *The behaviour of organisms.* Appleton-Century-Crofts, Nueva York, 1938.

97. Skinner, B.F., *Contingencies of reinforcement: A theoretical analysis*. Vol. 3. 2014: BF Skinner Foundation.

98. James, W., *1950. The principles of psychology*. 1890, New York: Dover.

99. Opsahl, R.L. and M.D. Dunnette, *Role of financial compensation in industrial motivation.* Psychological bulletin, 1966. **66**(2): p. 94.

100. White, K. and D.R. Lehman, *Culture and social comparison seeking: The role of self-motives.* Personality and Social Psychology Bulletin, 2005. **31**(2): p. 232-242.

101. Zimbardo, P.G., *Lucifer effect*. 2007: Wiley Online Library.

102. Kunz, A.H. and D. Pfaff, *Agency theory, performance evaluation, and the hypothetical construct of intrinsic motivation.* Accounting, organizations and society, 2002. **27**(3): p. 275-295.

103. Schuster, J.R., B. Clark, and M. Rogers, *Testing portions of the Porter and Lawler model regarding the motivational role of pay.* Journal of Applied Psychology, 1971. **55**(3): p. 187.

104. Camerer, C.F., et al., *The effects of financial incentives in experiments: A review and capital-labor-production framework*, in *Elicitation of Preferences*. 1999, Springer. p. 7-48.

105. Lawler, E.E. and L.W. Porter, *Antecedent attitudes of effective managerial performance.* Organizational behavior and human performance, 1967. **2**(2): p. 122-142.

106. Deci, E.L., *Effects of externally mediated rewards on intrinsic motivation.* Journal of personality and Social Psychology, 1971. **18**(1): p. 105.

107. Studer, B. and S. Knecht, *A benefit–cost framework of motivation for a specific activity.* Progress in Brain Research, 2016. **229**: p. 25-47.

108. Schunk, D.H., J.R. Meece, and P.R. Pintrich, *Motivation in education: Theory, research, and applications*. 2012: Pearson Higher Ed.

109. Cook, D.A. and A.R. Artino, *Motivation to learn: an overview of contemporary theories.* Medical education, 2016. **50**(10): p. 997-1014.

110. Deci, E.L. and R.M. Ryan, *Handbook of self-determination research*. 2002: University Rochester Press.

111. Deci, E.L. and R.M. Ryan, *The "What" and "Why" of Goal Pursuits: Human Needs and the Self-determination of Behavior.* Psychological inquiry, 2000. **11**(4): p. 227-268.

112. Fisher, C.D., *The effects of personal control, competence, and extrinsic reward systems on intrinsic motivation.* Organizational Behavior and Human Performance, 1978. **21**(3): p. 273-288.

113. Csikszentmihalyi, M., *Beyond boredom and anxiety. San Francisco: JosseyBass.* Well-being: Thefoundations of hedonic psychology, 1975: p. 134-154.

114. Boggiano, A.K. and D.N. Ruble, *Competence and the overjustification effect: A developmental study.* Journal of Personality and Social Psychology, 1979. **37**(9): p. 1462.

115. Buchanan, J.M., *Cost and choice: An inquiry in economic theory*. 1979: University of Chicago Press.

116. Buchanan, J.M., *Opportunity cost*. The New Palgrave Dictionary of Economics, ed. S.N.D.a.L.E. Blume. Vol. Second Edition. 2008, Palgrave Macmillan: The New Palgrave Dictionary of Economics Online.

117. Kilduff, G.J., *Driven to win rivalry, motivation, and performance.* Social Psychological and Personality Science, 2014. **5**(8): p. 944-952.

118. Karmarkar, U.S., *Subjectively weighted utility: A descriptive extension of the expected utility model.* Organizational behavior and human performance, 1978. **21**(1): p. 61-72.

119. Crockett, M.J. and E. Fehr, *Social brains on drugs: tools for neuromodulation in social neuroscience.* Social cognitive and affective neuroscience, 2013: p. nst113.

120. Bos, P.A., et al., *Acute effects of steroid hormones and neuropeptides on human social–emotional behavior: a review of single administration studies.* Frontiers in neuroendocrinology, 2012. **33**(1): p. 17-35.

121. Eisenegger, C., J. Haushofer, and E. Fehr, *The role of testosterone in social interaction.* Trends in cognitive sciences, 2011. **15**(6): p. 263-271.

122. Vermeer, A.L., I. Riečanský, and C. Eisenegger, *Competition, testosterone, and adult neurobehavioral plasticity.* Progress in Brain Research, 2016. **229**: p. 213-238.

123. Deci, E.L., et al., *When trying to win competition and intrinsic motivation.* Personality and social psychology bulletin, 1981. **7**(1): p. 79-83.

124. Stanne, M.B., D.W. Johnson, and R.T. Johnson, *Does competition enhance or inhibit motor performance: A meta-analysis.* Psychological Bulletin, 1999. **125**(1): p. 133-154.

125. Goeree, J.K., C.A. Holt, and T.R. Palfrey, *Quantal response equilibrium and overbidding in private-value auctions.* Journal of Economic Theory, 2002. **104**(1): p. 247-272.

126. Kagel, J.H. and D. Levin, *Independent Private Value Auctions - Bidder Behavior in 1st-Price, 2nd-Price and 3rd-Price Auctions with Varying Numbers of Bidders.* Economic Journal, 1993. **103**(419): p. 868-879.

127. Cox, J.C., B. Roberson, and V.L. Smith, *Theory and behavior of single object auctions.* Research in experimental economics, 1982. **2**(1): p. 1-43.

128. Kagel, J.H., R.M. Harstad, and D. Levin, *Information impact and allocation rules in auctions with affiliated private values: A laboratory study.* Econometrica: Journal of the Econometric Society, 1987: p. 1275-1304.

129. Cox, J.C., V.L. Smith, and J.M. Walker, *Theory and individual behavior of first-price auctions.* Journal of Risk and uncertainty, 1988. **1**(1): p. 61-99.

130. Burguillo, J.C., *Using Game Theory and Competition-based Learning to Stimulate Student Motivation and Performance.* Computers & Education, 2010. **55**(2): p. 566-575.

131. Van Nuland, S.E., et al., *Head to head: The role of academic competition in undergraduate anatomical education.* Anatomical sciences education, 2015. **8**(5): p. 404-412.

132. Cagiltay, N.E., E. Ozcelik, and N.S. Ozcelik, *The Effect of Competition on Learning in Games.* Computers & Education, 2015. **87**: p. 35-41.

133. Bergin, S. and R. Reilly, *The Influence of Motivation and Comfort-level on Learning to Program.* 2005.

134. DiMenichi, B.C. and E. Tricomi, *The power of competition: Effects of social motivation on attention, sustained physical effort, and learning.* Frontiers in Psychology, 2015. **6**.

135. Giannini, J.M., R.S. Weinberg, and A.J. Jackson, *The effects of mastery, competitive, and cooperative goals on the performance of simple and complex basketball skills.* Journal of Sport and Exercise Psychology, 1988. **10**: p. 408-417.

136. Williams, E.L., et al., *Competitor presence reduces internal attentional focus and improves 16.1km cycling time trial performance.* J Sci Med Sport, 2015. **18**(4): p. 486-91.

137. Noonan, M.P., et al., *Re-evaluating the role of the orbitofrontal cortex in reward and reinforcement.* European Journal of Neuroscience, 2012. **35**(7): p. 997-1010.

138. Studer, B., et al., *Risk-sensitive decision-making in patients with posterior parietal and ventromedial prefrontal cortex injury.* Cereb Cortex, 2015. **25**(1): p. 1-9.

139. Rushworth, M.F., et al., *Frontal cortex and reward-guided learning and decision-making.* Neuron, 2011. **70**(6): p. 1054-69.

140. Kennerley, S.W. and M.E. Walton, *Decision making and reward in frontal cortex: complementary evidence from neurophysiological and neuropsychological studies.* Behav Neurosci, 2011. **125**(3): p. 297-317.

141. Volz, K.G., R.I. Schubotz, and D.Y. von Cramon, *Decision-making and the frontal lobes.* Curr Opin Neurol, 2006. **19**(4): p. 401-6.

142. O'Doherty, J.P., *Reward representations and reward-related learning in the human brain: insights from neuroimaging.* Current Opinion in Neurobiology, 2004. **14**(6): p. 769-776.

143. Fareri, D.S. and M.R. Delgado, *Differential reward responses during competition against in- and out-of-network others.* Soc Cogn Affect Neurosci, 2014. **9**(4): p. 412-20.

144. Le Bouc, R. and M. Pessiglione, *Imaging social motivation: distinct brain mechanisms drive effort production during collaboration versus competition.* J Neurosci, 2013. **33**(40): p. 15894-902.

145. Carré, J.M. and N.A. Olmstead, *Social neuroendocrinology of human aggression: examining the role of competition-induced testosterone dynamics.* Neuroscience, 2015. **286**: p. 171-186.

146. Zilioli, S. and N.V. Watson, *Testosterone across successive competitions: Evidence for a 'winner effect' in humans?* Psychoneuroendocrinology, 2014. **47**: p. 1-9.

147. Mazur, A. and A. Booth, *Testosterone and dominance in men.* Behavioral and Brain Sciences, 1998. **21**(3): p. 353-+.

148. Mazur, A., *A biosocial model of status in face-to-face primate groups.* Social Forces, 1985. **64**(2): p. 377-402.

149. Burger, H.G., *Androgen production in women.* Fertility and sterility, 2002. **77**: p. 3-5.

150. Suay, F., et al., *Effects of competition and its outcome on serum testosterone, cortisol and prolactin.* Psychoneuroendocrinology, 1999. **24**(5): p. 551-566.

151. Williams, R.B., et al., *Type A behavior and elevated physiological and neuroendocrine responses to cognitive tasks.* Science, 1982. **218**(4571): p. 483-485.

152. Zumoff, B., et al., *Elevated daytime urinary excretion of testosterone glucuronide in men with the type A behavior pattern.* Psychosomatic medicine, 1984. **46**(3): p. 223-225.

153. Bhasin, S., et al., *Testosterone therapy in adult men with androgen deficiency syndromes: an endocrine society clinical practice guideline.* The Journal of Clinical Endocrinology & Metabolism, 2006. **91**(6): p. 1995-2010.

154. Tauer, J.M. and J.M. Harackiewicz, *Effects of cooperation and competition on intrinsic motivation and performance (vol 86, pg 849, 2004).* Journal of Personality and Social Psychology, 2004. **87**(2): p. 245-245.

155. Elliot, A.J. and M.A. Church, *A hierarchical model of approach and avoidance achievement motivation.* Journal of personality and social psychology, 1997. **72**(1): p. 218.

156. Delgado, M.R., et al., *Understanding overbidding: using the neural circuitry of reward to design economic auctions.* Science, 2008. **321**(5897): p. 1849-1852.

157. Engelbrecht-Wiggans, R. and E. Katok, *E-sourcing in procurement: Theory and behavior in reverse auctions with noncompetitive contracts.* Management Science, 2006. **52**(4): p. 581-596.

158. Filiz-Ozbay, E. and E.Y. Ozbay, *Auctions with anticipated regret: Theory and experiment.* American Economic Review, 2007. **97**(4): p. 1407-1418.

159. Johnson, D.W. and R.T. Johnson, *Instructional Goal Structure - Cooperative, Competitive, or Individualistic.* Review of Educational Research, 1974. **44**(2): p. 213-240.

160. Salvador, A., *Coping with competitive situations in humans.* Neuroscience and Biobehavioral Reviews, 2005. **29**(1): p. 195-205.

161. Salvador, A. and R. Costa, *Coping with competition: Neuroendocrine responses and cognitive variables.* Neuroscience and Biobehavioral Reviews, 2009. **33**(2): p. 160-170.

162. Borg, G., *Perceived exertion as an indicator of somatic stress.* Scand J Rehabil Med, 1970. **2**(2): p. 92-8.

163. Löllgen, H., U. Fahrenkrog, and D. Löllgen, *Allgemeine Aspekte ergometrischer Messgrößen*, in *Ergometrie: Belastungsuntersuchungen in Klink und Praxis*, H. Löllgen, E. Erdmann, and A.K. Gitt, Editors. 2010, Springer Berlin Heidelberg: Berlin, Heidelberg. p. 61-84.

164. Löllgen, H. and H. Ulmer, *Ergometrie—Empfehlungen zur Durchführung und Bewertung ergometrischer Untersuchungen.* Klinische Wochenschrift, 1985. **63**(14): p. 651-677.

165. Borg, G. and H. Linderholm, *Exercise Performance and Perceived Exertion in Patients with Coronary Insufficiency, Arterial Hypertension and Vasoregulatory Asthenia.* Acta Medica Scandinavica, 1970. **187**(1-2): p. 17-+.

166. Löllgen, H., *Kardiopulmonale Funktionsdiagnostik*. 2005: Novartis Pharma.

167. Wilmore, J.H.C., D. L. , *Physiology of Exercise and Sport.* Champaign, IL: Human Kinetics,, 1994.

168. Machado, F.A. and B.S. Denadai, *Validity of maximum heart rate prediction equations for children and adolescents.* Arquivos brasileiros de cardiologia, 2011. **97**(2): p. 136-140.

169. Tanaka, H., K.D. Monahan, and D.R. Seals, *Age-predicted maximal heart rate revisited.* Journal of the American College of Cardiology, 2001. **37**(1): p. 153-156.

170. Liang, K.-Y. and S.L. Zeger, *Longitudinal data analysis using generalized linear models.* Biometrika, 1986. **73**(1): p. 13-22.

171. Zeger, S.L. and K.-Y. Liang, *Longitudinal data analysis for discrete and continuous outcomes.* Biometrics, 1986: p. 121-130.

172. Zeger, S.L., K.-Y. Liang, and P.S. Albert, *Models for longitudinal data: a generalized estimating equation approach.* Biometrics, 1988: p. 1049-1060.

173. Potempa, K., et al., *Physiological Outcomes of Aerobic Exercise Training in Hemiparetic Stroke Patients.* Stroke, 1995. **26**(1): p. 101-105.

174. Woodman, T., et al., *Self-confidence and performance: A little self-doubt helps.* Psychology of Sport and Exercise, 2010. **11**(6): p. 467-470.

175. van de Pol, P.K., M. Kavussanu, and C. Ring, *The effects of training and competition on achievement goals, motivational responses, and performance in a golf-putting task.* Journal of Sport and Exercise Psychology, 2012. **34**(6): p. 787.

176. Reeve, J. and E.L. Deci, *Elements of the competitive situation that affect intrinsic motivation.* Personality and Social Psychology Bulletin, 1996. **22**: p. 24-33.

177. Reeve, J., B.C. Olson, and S.G. Cole, *Motivation and Performance - 2 Consequences of Winning and Losing in Competition.* Motivation and Emotion, 1985. **9**(3): p. 291-298.

178. Vallerand, R.J., L.I. Gauvin, and W.R. Halliwell, *Effects of Zero-Sum Competition on Childrens Intrinsic Motivation and Perceived Competence.* Journal of Social Psychology, 1986. **126**(4): p. 465-472.

179. Deci, E.L., *The psychology of self-determination*. 1980: Free Press.

180. Fitts, P.M. and M.I. Posner, *Human performance.* 1967.

181. Chiviacowsky, S. and G. Wulf, *Feedback after good trials enhances learning.* Research Quarterly for Exercise and Sport, 2007. **78**(2): p. 40-47.

182. Chiviacowsky, S., et al., *Knowledge of results after good trials enhances learning in older adults.* Research Quarterly for Exercise and Sport, 2009. **80**(3): p. 663-668.

183. Badami, R., et al., *Feedback after good versus poor trials affects intrinsic motivation.* Research quarterly for exercise and sport, 2011. **82**(2): p. 360-364.

184. Nicholls, J.G., *Achievement motivation: Conceptions of ability, subjective experience, task choice, and performance.* Psychological review, 1984. **91**(3): p. 328.

185. Dweck, C.S., *Motivational processes affecting learning.* American psychologist, 1986. **41**(10): p. 1040.

186. Fareri, D.S. and M.R. Delgado, *Differential reward responses during competition against in-and out-of-network others.* Social cognitive and affective neuroscience, 2014. **9**(4): p. 412-420.

187. Baumeister, R.F. and M.R. Leary, *The need to belong: desire for interpersonal attachments as a fundamental human motivation.* Psychological bulletin, 1995. **117**(3): p. 497.

188. Fehr, E. and A. Falk, *Reciprocal fairness, cooperation and limits to competition.* Intersubjectivity in Economics, London: Routledge, 2002: p. 28-42.

189. Eston, R. and J. Williams, *Reliability of ratings of perceived effort regulation of exercise intensity.* British journal of sports medicine, 1988. **22**(4): p. 153-155.

190. Borg, G., *Ratings of Perceived Exertion and Heart-Rates during Short-Term Cycle Exercise and Their Use in a New Cycling Strength Test.* International Journal of Sports Medicine, 1982. **3**(3): p. 153-158.

191. Fritz, T.H., et al., *Musical agency reduces perceived exertion during strenuous physical performance.* Proceedings of the National Academy of Sciences, 2013. **110**(44): p. 17784-17789.

192. Kreibig, S.D., *Autonomic Nervous System Activity in Emotion: A Review.* Biological psychology, 2010. **84**(3): p. 394-421.

193. Mulder, L., *Measurement and analysis methods of heart rate and respiration for use in applied environments.* Biological psychology, 1992. **34**(2): p. 205-236.

194. Mehrholz, J. and M. Pohl, *Wird in der neurologischen Rehabilitation seitens der Physiotherapie ausreichend das Herz-Kreislaufsystem trainiert.* Ein Vergleich verschiedener Übungen bei gehfähigen Patienten mit Hemiparese nach Schlaganfall. Neurologie und Rehabilitation, 2005. **11**: p. 126-130.

195. Adams, R.J., et al., *Coronary risk evaluation in patients with transient ischemic attack and ischemic stroke.* Circulation, 2003. **108**(10): p. 1278-1290.

196. Duncan, P., et al., *Randomized clinical trial of therapeutic exercise in subacute stroke.* Stroke, 2003. **34**(9): p. 2173-2180.

197. Baumeister, R.F. and C.J. Showers, *A Review of Paradoxical Performance Effects - Choking under Pressure in Sports and Mental Tests.* European Journal of Social Psychology, 1986. **16**(4): p. 361-383.

198. van Almenkerk, S., et al., *Apathy among institutionalized stroke patients: prevalence and clinical correlates.* Am J Geriatr Psychiatry, 2015. **23**(2): p. 180-8.

199. Bernoulli, D., *Exposition of a new theory on the measurement of risk.* Econometrica: Journal of the Econometric Society, 1954: p. 23-36.

200. Edwards, W., *Behavioral decision theory.* Annual review of psychology, 1961. **12**(1): p. 473-498.

201. Edwards, W., *Utility, subjective probability, their interaction, and variance preferences.* Journal of Conflict Resolution, 1962. **6**(1): p. 42-51.

202. Harris, P.B. and J.M. Houston, *A reliability analysis of the revised competitiveness index.* Psychological reports, 2010. **106**(3): p. 870-874.

203. Harris, N., J. Newby, and R.G. Klein, *Competitiveness facets and sensation seeking as predictors of problem gambling among a sample of university student gamblers.* Journal of Gambling Studies, 2015. **31**(2): p. 385-396.

204. Smither, R.D. and J.M. Houston, *The nature of competitiveness: The development and validation of the competitiveness index.* Educational and Psychological Measurement, 1992. **52**(2): p. 407-418.

205. Marsh, H.W., *Sport motivation orientations: Beware of jingle-jangle fallacies.* Journal of Sport & Exercise Psychology, 1994. **16**(4): p. 365-380.

206. Kim, S.-i., Johnmarshall Reeve, and M. Bong, *Introduction to Motivational Neuroscience.* Recent Developments in Neuroscience Research on Human Motivation, 2016. **19**(Advances in Motivation and Achievement book series): p. pp. 1-19.

9. Annex

I. Measurement protocol for the performance diagnostics

Messprotokoll Leistungsdiagnostik Bewegungstrainer

Datum:

Uhrzeit:

Name des Patienten____

Geburtstag___________________

Größe_______________________ Gewicht____________________

Erstmessung____________________Wiederholungsmessung________

Unterschrift Stationsarzt: ja____ nein____

Absolute Kontraindikation: ja____ nein____ (→ Abbruch!)

ß-Blocker Medikation: ja____ nein____

wenn **JA**, welche? ____

Ruhepuls ____________		Belastungsstufen zu je 1 Minute; Abbruch, wenn Puls >160/ min			
Belastung	1 Minute	2 Minuten	3 Minuten	4 Minuten	
26 Watt					Puls nach Belastungsende unter 130/min? Ja→ nächste Stufe Nein→ Abbruch
50 Watt					Puls nach Belastungsende unter 130/min?

					Ja→ nächste Stufe Nein→ Abbruch
76 Watt					Puls nach Belastungsende unter 130/min? Ja→ nächste Stufe Nein→ Abbruch
Minuten bis Puls < 100					
Sonstige Anmerkungen					

min = Minute; ß-Blocker = Beta-Blocker

II. Questionnaire for the Treating Physician

Stationsarztbogen für die Studie " Ausdauer-Eigentraining nach Schlaganfall"

Studienleiterin: Frau Dr. Studer; Untersucherin: Rebecca Handermann

Liebe Stationsärztin/ lieber Stationsarzt,

Bei dem unten genannten Patienten soll ein Belastungstest auf dem Bewegungstrainer zur Erhebung der kardiorespiratorischen Fitness durchgeführt werden. Wir bitten Sie, anhand der unten gelisteten Kontraindikationen zu prüfen ob der/ die Patient/in für die Diagnostik geeignet ist.

Bitte legen Sie den ausgefüllten Bogen zurück in Ihr Fach auf Station.

Vielen Dank!

Patienten Name: ____

Station: ____

Bekommt der Patient Beta-Blocker Medikamente: ja____ nein____

Wenn **ja**, welche____?

Kontraindikationen bekannt	JA	NEIN
Instabile Angina Pectoris, zunehmende Atemnot, klinische/ subjektive Verschlechterung der Belastungstoleranz in den letzten Tagen		
Progrediente Rechtsherzdekompensation		
Gewichtszunahme von mehr als 1,5 kg in den letzten 3 Tagen		
Nicht kontrollierbare RR-Entgleisung		
Nicht kontrollierbare BZ-Entgleisung (Keton positiv)		
Akut entzündliche Herzerkrankung (Akute Peri-, Myo-, und		

Endokarditis)		
Herzinsuffizienz oder KHK Stadium NYHA IV		
Symptomatische bzw. hochgradige Aortenklappenstenose		
Symptomatische HCM (hypertrophe Kardiomyopathie)		
Koronare Herzkrankheit mit belastungsinduzierbaren Rhythmusstörungen oder zusätzlicher linksventrikulärer Funktionseinschränkung (EF< 50%)		
Fieber, akute Infektionen, frisches embolisches Ereignis oder TVT (aufgetreten nach Aufnahme in MTK)		
Herzinsuffizienz nach Myokardinfarkt in den letzten 3 Wochen		
Neu aufgetretenes Vorhofflimmern/ Flattern (Diagnostik und Akutbehandlung nicht abgeschlossen)		
Ruhedyspnoe		
Ausgeprägte kognitive Störung (Mini-Mental-State < 20)		
Mittel- schwergradige Aphasie		
Einzelzimmer-Isolation aufgrund von multiresistenten Keimen		
(verbleibender) stationärer Aufenthalt dauert voraussichtlich weniger als 2 Wochen		

TVT = Tiefe Veinbenenthrombose; MTK= Mauritius Therapieklinik; KHK= koronare Herzkrankheit; RR = Blutdruck; EF = Ejektionsfraktion; NYHA IV= *New York Heart association classification* (zur Beurteilung einer Herzinsuffizienz) Klasse 4; kg = Kilogramm; BZ = Blutzucker

III. Measurement Protocol for Training Performance in the Baseline, Feedback and Competition Condition

	Teilnehmer ID				
	Alter	Geschlecht	Datum	Trainingsleistung	Borg-Skala
B1					
B2					
B3					

	Teilnehmer ID				
	Alter	Geschlecht	Datum	Trainingsleistung	Borg-Skala
R1					
R2					
R3					

. B = Baseline, R = Feedback, W = Competition

	Teilnehmer ID				
	Alter	Geschlecht	Datum	Trainingsleistung	Borg-Skala
W1					
W2					
W3					

	Gegner Daten			
	Alter	Geschlecht	Datum	Trainingsleistung
W1				
W2				
W3				

IV. Patient Questionnaire for the Competition Study

Name: ______________________________

Geburtsdatum: _______________________

Diagnose: ___________________________

Komorbidität: ________________________

Einschlusskriterien

Kortikaler oder subkortikaler Schlaganfall vor mindestens 2 und maximal 20 Wochen	
Deutschsprachig	
Alter >18	
Mobilität: selbständig mobil, mit oder ohne Hilfsmittel (inklusive Rollstuhl)	
Beinfunktion soweit erhalten, dass Training auf Bewegungstrainer möglich	
Einwilligungsfähig	
Kreislauf stabil	

Ausschlusskriterien

Vorhandene Kontraindikationen für Leistungsdiagnostik	
Ausgeprägte kognitive Störung	
Mittel- bis schwergradige Aphasie	
(verbleibender) stationärer Aufenthalt dauert voraussichtlich weniger als 2 Wochen	
Einzelzimmer-Isolation aufgrund multi-resistenter keime	

Unterschrift: ____

V. Borg-Scale and Instructions

Anstrengungsempfinden

6	Überhaupt nicht anstrengend
7	
	Extrem leicht
8	
9	Sehr leicht
10	
11	Leicht
12	
13	Etwas anstrengend
14	
15	Anstrengend/ Schwer
16	
17	Sehr anstrengend
18	
19	Extrem anstrengend
20	Maximal anstrengend

modified from [17]

Anleitung Borg-RPE-Skala

Wir wollen Ihr Anstrengungsempfinden während des Trainings bestimmen. Das heißt, wir wollen feststellen, wie anstrengend das Treten auf dem Bewegungstrainer ist. Das Anstrengungsempfinden hängt von der Beanspruchung und Ermüdung der Muskulatur ab, ferner von Atemlosigkeit (beziehungsweise Luftnot) oder brustschmerzen ab.

Auf der Skala bedeutet **6:** überhaupt nicht anstrengend und **20** bedeutet maximale Anstrengung.

9: entspricht einer sehr leichten Anstrengung, wie bei einer Normalperson das Gehen im eigenen Tempo

13: auf der Skala ist „etwas anstrengend“, man kann bei der Belastung aber gut weitermachen

15: ist „anstrengend“ und „schwer“, aber Fortfahren ist noch möglich

17: „sehr anstrengend“. Sie können das Training noch weitermachen, sie müssen sich aber sehr anstrengen und sind bald erschöpft.

19: „sehr sehr anstrengend“, für die meisten Personen ist dies eine sehr anstrengende Belastung, die stärkste, die sie jemals erlebt haben.

Versuchen Sie, Ihr Anstrengungsempfinden so spontan und ehrlich wie möglich anzugeben, ohne über die aktuelle Belastung nachzudenken.

Versuchen Sie, die Anstrengung weder zu über- noch zu unterschätzen. Ihre eigene Empfindung von Leistung und Anstrengung ist wichtig, nicht die im Vergleich zu anderen.

Schauen Sie auf der Skala und die begleitenden Worte und geben Sie eine Zahl an.

Modified from [17]

VI. Patient Information

Patienteninformationen Ausdauertraining nach Schlaganfall

Sehr geehrte Patientin, sehr geehrter Patient,

In Zusammenarbeit mit der Heinrich-Heine-Universität Düsseldorf führen wir in der St. Mauritius Therapieklinik eine systematische Untersuchung zum Training der kardiorespiratorischen Ausdauer nach Schlaganfall durch.

Bitte lesen Sie die folgenden Informationen über die Untersuchung und fragen Sie nach, falls etwas unklar sein sollte. Ihre Teilnahme an dieser Studie ist freiwillig und Sie können von der Teilnahme jederzeit zurücktreten.

Um was geht es?

Ihr Arzt/ Ihre Ärztin und Ihr Physiotherapeut/ Ihre Physiotherapeutin hat Ihnen empfohlen, ein Eigentraining auf dem Bewegungstrainer durchzuführen. Dieses Training dient dem Aufbau der kardio-respiratorischen Ausdauer und Kraft. Derzeit führen wir eine Datenerhebung zum Eigentraining durch. Ziel ist es, zu erfassen, wie wirksam und wie anstrengend das Eigentraining ist. Des Weiteren untersuchen wir, welche motivationalen Faktoren wichtig sind und wie die Trainingsmotivation am besten gefördert werden kann.

Was geschieht in der Studie?

Sie führen wie gewohnt selbstständig ein Training zur Verbesserung der Ausdauer am Bewegungstrainer durch. Für die Studie wird dabei Ihre Trainingsaktivität durch einen kleinen Schrittzähler und durch das Trainingsgerät erfasst. Möglicherweise werden wir Sie bitten, zusätzlich ein Puls-Messgerät zu tragen. Vor und nach dem Training treffen Sie sich jeweils zu einer kurzen Besprechung mit der Untersucherin. An einigen Tagen findet das Eigentraining im Rahmen eines sportlichen Wettbewerbs statt. Dabei wird Ihnen ein anderer Patient mit einem ähnlichen Fitness- und Trainingslevel als anonymer Gegner zugeordnet. Die Identität des Gegners wissen Sie nicht und Ihre eigene Anonymität wird ebenfalls gewährleistet.

Dazu kommen noch zwei Untersuchungen, eine Vor- und eine Nachuntersuchung am Ende Ihrer Teilnahme. In diesen Untersuchungen wird Ihre kardio-respiratorische Ausdauer durch einen sogenannten Leistungstest gemessen. Der Leistungstest findet auf dem Bewegungstrainer unter Begleitung statt. Ihr behandelnder Arzt oder Ärztin überprüft vorab sorgfältig, ob Sie für diesen Test geeignet sind. Des Weiteren wird Ihre Persönlichkeit und Gemütslage mittels einiger kurzen Fragebögen erfasst.

Wie lange dauert die Studie?

Die Studie dauert in der Regel bis zum Ende Ihres Aufenthaltes in der Klinik, mindestens aber zwei Wochen.

Was sind die Risiken dieser Erhebung?

Bei Teilnahme an der Untersuchung entstehen Ihnen keine zusätzlichen Risiken. Bei Herzerkrankungen (koronare Herzkrankheit, Herzinsuffizienz, „symptomatische Kardiomyopathie“) ist Sporttherapie mit einem erhöhten Risiko von Herz-Kreislauf-Komplikationen verbunden. Falls Sie an einer dieser Herzerkrankungen leiden, ist diese Untersuchung für Sie daher ungeeignet.

Wer kann nicht an der Untersuchung teilnehmen?

Nicht teilnehmen können Patienten mit den obigen Herzerkrankungen, Kinder und Jugendliche, Patienten mit deutlichen Sprachstörungen und Patienten in Einzelzimmer-Isolation. Eine weitere Voraussetzung für die Teilnahme ist, dass Ihr Aufenthalt in der St. Mauritius Therapieklinik voraussichtlich noch mindestens 2 Wochen dauert.

Was für Vorteile habe ich, wenn ich an der Erhebung teilnehme?

Ein unmittelbarer persönlicher Vorteil entsteht Ihnen nicht. Im Rahmen der Teilnahme an der Studie erhalten Sie allerdings eine Trainingsbegleitung und Rückmeldung über die aufgenommenen Daten. So können Sie mitverfolgen, wie sich Ihre Trainingsleistung, Ausdauer und Kraft über die Zeit entwickeln.

Teilnahme und Widerruf der Teilnahme

Ihre Teilnahme ist freiwillig. Sie können die Teilnahme an der Studie jederzeit abbrechen. Sollten Sie nicht teilnehmen wollen, wird die Ihnen zustehende Behandlung in der St. Mauritius Therapieklinik in keiner Weise negativ beeinflusst.

Vertraulichkeit der Daten und wissenschaftliche Nutzung der Forschungsergebnisse

Ausschließlich die Mitglieder des Forschungsteams und die behandelnden Ärzte, Therapeuten und das Pflegepersonal wissen, dass Sie Studienteilnehmer/in sind. Alle Mitglieder des Forschungsteams sind Angestellte der St. Mauritius Therapieklinik oder des Studienpartner Heinrich-Heine-Universität Düsseldorf und unterstehen der ärztlichen Schweigepflicht.

Die Ergebnisse der Untersuchung werden in anonymisierter Form in Fachzeitschriften veröffentlicht und auf Konferenzen vorgestellt. Es ist nicht möglich, Sie anhand dieser anonymisierten Daten zu identifizieren.

Abbruch durch den Untersucher

Die Untersucherin oder Ihr behandelnder Arzt kann die Untersuchung unterbrechen oder abbrechen, wenn relevante Gründe auftreten. Dies wäre zum Beispiel der Fall, wenn Sie im Zeitraum der Untersuchung einen Infekt mit hohem Fieber bekommen.

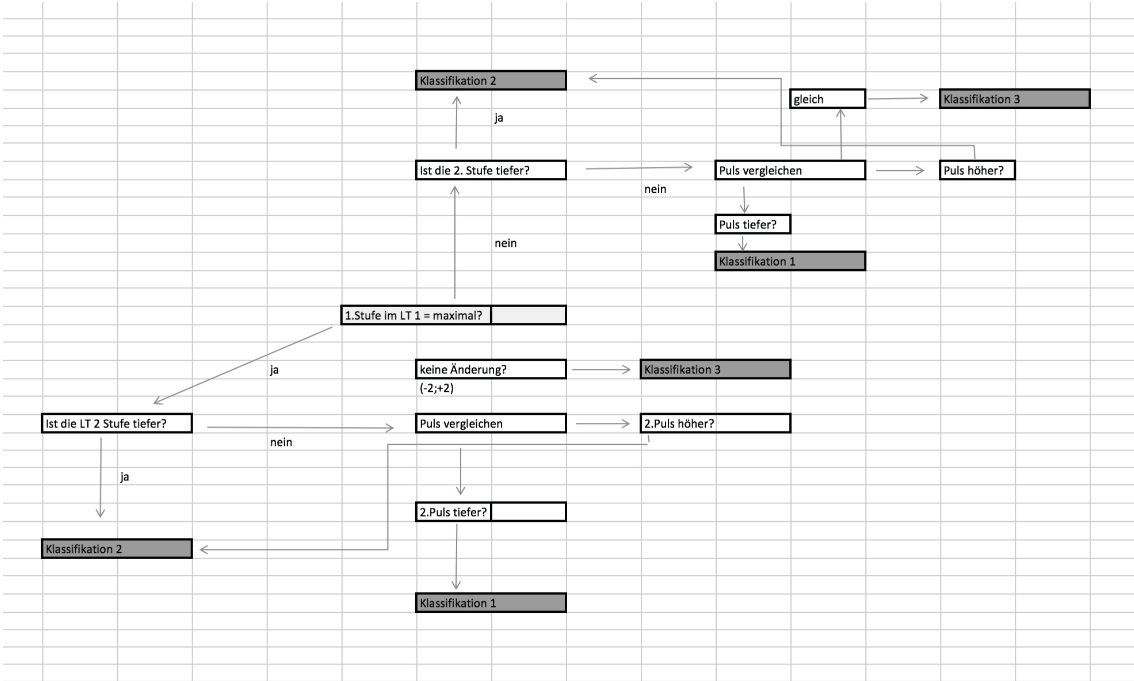
Versicherung

Es wurde keine Probanden-Versicherung abgeschlossen. Patienten, welche sich auf Kosten einer gesetzlichen Krankenkasse oder eines Trägers der gesetzlichen Rentenversicherung in stationärer Behandlung in der St. Mauritius Therapieklinik befinden, sind gesetzlich unfallversichert gemäß §2 Abs. 1 Nr. 15a SGB VII. Wird Ihre stationäre Behandlung nicht durch eine gesetzliche Krankenkasse oder eine gesetzliche Rentenversicherung getragen, sind Sie bei unverschuldet auftretenden Gesundheitsschäden nicht versichert. Für privatversicherte Patienten besteht Versicherungsschutz gemäß dem privat abgeschlossenen Vertrag mit Ihrer Krankenkasse. Allfällige vom Personal verschuldete Schäden unterliegen der Haftpflichtversicherung der St. Mauritius Therapieklinik.

Weitere Informationen

Falls Sie noch Frage zur Studie haben, wenden Sie sich bitte an die Untersucherin oder an die Studienleiterin, Fr. Dr. Studer.

VII. Instructions for the Classification of Performance Tests



1 = Verbesserung/ Improvement; 2 = Verschlechterung/ Worsening; 3 = keine Veränderung/ no change

VIII. Results of GEE Model Analysis on standardized Training Performance

Deskriptive Statistik

	N	Mittelwert	Standardabweichung
Messergebnis in Joules/Tritten	636	25565,48	23624,856
Gültige Werte (Listenweise)	636		

Verallgemeinerte lineare Modelle

Modellinformationen

Abhängige Variable		z-Faktorwert(Schritte) Messergebnis in Joules/Tritten
Wahrscheinlichkeitsverteilung		Normal
Verknüpfungsfunktion		Identität
Subjekteffekt	1	Probanden ID
Struktur der Arbeitskorrelationsmatrix		Unabhängig

Korrelierte Datenzusammenfassung

Anzahl der Niveaus	Subjekteffekt	Probanden ID	63
Anzahl der Subjekte			63
Anzahl der Messungen pro Subjekt	Minimum		5
	Maximum		29
Dimension der Korrelationsmatrix			29

Zusammenfassung der Fallverarbeitung

	N	Prozent
Eingeschlossen	636	100,0%
Ausgeschlossen	0	0,0%
Gesamt	636	100,0%

Informationen zu kategorialen Variablen

			N	Prozent
Faktor	Bedingungsbezeichnung	Wettbewerb	208	32,7%
		Rückmeldung	225	35,4%
		Baseline	203	31,9%
		Gesamt	636	100,0%

Informationen zu stetigen Variablen

		N	Minimum	Maximum	Mittelwert
Abhängige Variable	z-Faktorwert(Schritte) Messergebnis in Joules/Tritten	636	-1,07833	4,92678	,0000000
Kovariate	Tage vergangen seit Beginn der Messungen	636	0	63	12,43

Informationen zu stetigen Variablen

		Standardabweichung
Abhängige Variable	z-Faktorwert(Schritte) Messergebnis in Joules/Tritten	1,00000000
Kovariate	Tage vergangen seit Beginn der Messungen	12,342

	Wert
Quasi-Likelihood unter Unabhängigkeitsmodellkriterium	665,141
Korrigierte Quasi-Likelihood unter Unabhängigkeitsmodellkriterium	601,301

Tests der Modelleffekte

Quelle	Typ III		
	Wald-Chi-Quadrat	df	Sig.
(Konstanter Term)	8,964	1	,003
Bedingung	13,858	2	,001
Abstand	2,216	1	,137

Parameterschätzer

Parameter	Regressionskoeffizient B	Standardfehler	95% Wald-Konfidenzintervall		Hypothesentest
			Unterer Wert	Oberer Wert	Wald-Chi-Quadrat
(Konstanter Term)	-,304	,0750	-,451	-,157	16,400
[Bedingung=3]	,134	,0402	,055	,213	11,147
[Bedingung=2]	,027	,0530	-,077	,131	,266
[Bedingung=1]	0[a]	.	.	.	.
Abstand	,020	,0135	-,006	,047	2,216
(Skala)	,939				

Parameterschätzer

Parameter	Hypothesentest df	Hypothesentest Sig.
(Konstanter Term)	1	,000
[Bedingung=3]	1	,001
[Bedingung=2]	1	,606
[Bedingung=1]	.	.
Abstand	1	,137
(Skala)		

Geschätzte Randmittel: Bedingungsbezeichnung

Schätzer

			95% Wald-Konfidenzintervall	
Bedingungsbezeichnung	Mittelwert	Standardfehler	Unterer Wert	Oberer Wert
Wettbewerb	,0806778	2,21584714	-4,2623028	4,4236584
Rückmeldung	-,0262390	2,19621299	-4,3307374	4,2782593
Baseline	-,0535823	2,22199658	-4,4086155	4,3014510

Die im Modell erscheinenden Kovariaten werden auf folgende Werte festgesetzt: Abstand=12,43

Paarweise Vergleiche

(1) Bedingungsbezeichnung	(2) Bedingungsbezeichnung	Mittlere Differenz (1-2)	Standardfehler	df
Wettbewerb	Rückmeldung	,1069168[a]	,04505682	1
	Baseline	,1342601[a]	,04021343	1
Rückmeldung	Wettbewerb	-,1069168[a]	,04505682	1
	Baseline	,0273432	,05301519	1
Baseline	Wettbewerb	-,1342601[a]	,04021343	1
	Rückmeldung	-,0273432	,05301519	1

Paarweise Vergleiche

			95% Wald-Konfidenzintervall für die Differenz	
Bedingungsbezeichnung	Bedingungsbezeichnung	Sig.	Unterer Wert	Oberer Wert
Wettbewerb	Rückmeldung	,018	,0186071	,1952266
	Baseline	,001	,0554432	,2130769
Rückmeldung	Wettbewerb	,018	-,1952266	-,0186071
	Baseline	,606	-,0765646	,1312511
Baseline	Wettbewerb	,001	-,2130769	-,0554432
	Rückmeldung	,606	-,1312511	,0765646

Paarweise Vergleiche der geschätzten Randmittel auf der Grundlage der ursprünglichen Skala der abhängigen Variablen z-Faktorwert(Schritte) Messergebnis in Joules/Tritten

a. Die mittlere Differenz ist auf dem ,05-Niveau signifikant.

Gesamttestergebnisse

Wald-Chi-Quadrat	df	Sig.
13,858	2	,001

10. Acknowledgment

I would like to thank Dr. Bettina Studer and Prof. Dr. Alfons Schnitzler for entrusting me with the topic of this dissertation to me.

Foremost, I would like to express gratitude to my supervisor Dr. Bettina Studer for her great support during my doctoral thesis. Her patient guidance, encouragement and outstanding competence have been invaluable throughout all stages of this dissertation. The possibility to profit from her knowledge did help me a lot to accomplish my research project.

My very sincere thanks to Prof. Dr. med. Stefan Knecht for his great support during the study project, especially in terms of the study coordination during the phase of recruitment.

I would also like to thank Dr. Hanneke van Dijk and the research associates, the team of doctors and physiotherapists and all the staff of St. Mauritius hospital for their contribution and support during my dissertation.

Some special thanks are due to all patients of the St. Mauritius hospital for their participation in this study project and sacrificing their free time for me. Thanks for the fun we had and the motivating weekends we spent together. I am grateful for the valuable experiences I made at the St. Mauritius Hospital during my study project.

Finally, I am extremely grateful to my beloved parents - for their intellectual and financial support, for their understanding and re-encouragement throughout all the ups and downs of this study project.