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The quest for a bionic hand: recent achievements and future perspectives

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Replacing a missing upper limb with a functional one is an ancient need and desire. Historically, humans have replaced a missing limb with a prosthesis for many reasons, be it cosmetic, vocational, or for personal autonomy. The hand is a powerful tool and its loss causes severe physical and often mental debilitation. The need for a versatile prosthetic limb with intuitive motor control and realistic sensory feedback is huge and its development is absolutely necessary for the near future.

Among the possible solutions to achieve this goal, interfaces with the peripheral nervous system, and in particular intraneural electrodes, are a very promising choice. In this presentation, the results achieved so far by using thin-film transversal intraneural electrodes (TIMEs) for sensory feedback are summarized.

First, we are going to show the results achieved during a short-term implant of TIMEs in a trans-radial amputee to restore sensory feedback. With the first subject, it was possible to restore several component of the sense of touch such as contact events, grasping force, object shape and stiffness. We also showed that texture discrimination can be restored by implementing a neuromorphic algorithm reproducing the firing dynamics of nerve fibers connected to mechanoreceptors. Recent results achieved of the first long-term implant in another amputee confirm and extend previous results.

Finally, the next steps to achieve fully implantable devices will be briefly summarized.

These findings show that these interfaces are a valuable solution for delivering sensory feedback to subjects with transradial amputation. Further experiments are necessary to better understand the potentials of this approach during chronic experiments.

Standing in Balance on 3D L.A.S.A.R. Posture

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Introduction

The majority of orthopaedic fittings of the lower limb are influencing the geometry of the loaded structure. Physiologically the geometry is given, in orthopaedics the geometry must be optimized in relation to the function of the componentry. A new technical aid to optimize alignment under load is shown and background aspects are discussed.

Methods

Science uses the model of the inverted pendulum for human walking, although the centre of mass is moving almost constantly in gait, whereas the mass of a pendulum is reversing repetitively and so is showing alternating stopping and accelerating. Human standing does not "show" a moving mass, but the model of the inverted pendulum can be assigned to this activity directly. The models for walking and standing are compared and it is shown, how humans react to the physical challenge of standing. The technical aid, which consists of a unit acquiring two independent ground reaction forces and four independent cameras, indicates the force vectors of the ground reaction forces of both legs on an image of the standing person acquired in real-time. The angular adjustment of the foot shifts the COP indicated in an accuracy of +/- 1mm and hip moments tilt the force vector indicated in an accuracy of +-0,6° in typical loading conditions.

Results

The optimized orthopaedic fitting considers the balancing of the inverted pendulum. The geometrical optimization process can be defined and is described for TF prostheses as an example. Humans also use the properties of the inverted pendulum to effectively transient from standing to walking, in different strategies – depending to the time available.
The shown technical aid is supporting education effectively: Mimicking the loading condition of a user of an orthopaedic device, a not affected person can simulate the loading of the contralateral limb introduced by a unilateral fitting.

Conclusion

Systematic alignment for orthopaedic fittings, taking into account the loading conditions of the individual user, effectively supports those who are involved in the fitting; the orthopaedists and the physiotherapists. For the users of the fittings the improvement reaches from less stress during standing through easier balancing in walking.

Quality assessment of prosthesis alignments – mobile gait analysis with additional EEG measurements to evaluate required attention for walking

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Introduction

Prosthesis alignment is important for lower limb amputees, as it can have a great impact on their quality of life. A good alignment reduces the effort during gait and allows the amputee to pay attention to other tasks while walking. In order to optimize gait and alignment, a lot of research is aimed at the analysis of gait parameters. However, good quality in gait is a very individual criterion and until now not reliably assessable through an analysis of the biomechanical gait parameters. Thus it is the idea to gain additional and more objective information about the alignment quality through amputee's brain activity. The fundamental assumption is that with a better prosthesis alignment less attention for walking is demanded. If controlling the gait movements requires more attentional resources because of an inadequate prosthesis alignment, processing of an attention requiring secondary task at the same time would deteriorate due to insufficient resources. Through combined evaluation of both biomechanical gait parameters and brain dynamics reflecting attentional resource allocation in a secondary task, it should be possible to detect whether one prosthesis alignment is suitable for an amputee.

Methods

A case study was conducted focussing on the familiar prosthesis alignment and two variations (9 mm sagittal translation of the knee axis in anterior and posterior direction). Three subjects with a unilateral amputation and a microprocessor controlled prosthetic knee joint were included. The biomechanical gait parameters were collected with a mobile gait analysis system developed at Technische Universität Berlin together with research partners (current project: BeMobil, funded by BMBF, grant number 10042417). Additional EEG measurements were executed with a wireless EEG device (Smarting, mBrainTrain, Serbia) to assess changes in the amount of required cognitive resources during walking with different prosthesis alignments. During sitting (baseline condition) and walking periods participants had to attend to an auditory oddball task and to gather high frequent tones (target stimuli) with a tally counter. The P300 component, a positive deflection of the event-related potential with onset of target stimuli was evaluated.

Results

Due to the low number of participants, group statistics were not computed. Performance measurements of EEG data demonstrate no descriptive differences in the number of correct responses to target stimuli. The event-related potentials with onset of standard and target stimuli revealed clear differences in the auditory evoked P300 components for an individual subject. Target stimuli were accompanied by increased P300 amplitudes between 350 and 800ms. With the familiar prosthesis alignment, the P300 revealed earlier onset latencies and more pronounced amplitudes at electrode Pz as compared to the alignment variations. The biomechanical gait parameters also showed differences between the alignments in several aspects.

Conclusion

The aim of this study was to investigate if the described approach is an appropriate method to assess different prosthesis alignments. The participants tend to require more attention for walking with translation of the knee axis as compared to their familiar alignment. Initial results support the assumption that EEG could be a useful addition to mobile gait analysis to get indicators for quality of prosthetic gait. For improved statistical power, measurements with more subjects are necessary.

Novel Measure for Gait Quality Monitoring

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Introduction

Gait quality monitoring during the therapy of patients, who suffer from diseases which cause gait impartments such as neurodegenerative diseases (NDD), is essential for the evaluation of therapy effectiveness and maintaining the quality of life. IMUs have been widely used for recording the gait analysis parameters. However, most of the previous studies mainly focused on the investigation of the standard temporal-spatial parameters calculated from the acceleration data of the IMUs attached on the lower waist, and not enough attention has been paid on the variability of kinematic data. In this study, a novel measure for gait quality monitoring, based on the gait stability and gait uniformity features extracted from the measurement of the variability in shapes of the joint angle trajectories of individual gait cycles, is proposed. These features are inputs to the classifier, trained using machine learning techniques, which distinguishes impaired gait from the healthy one.

Methods

In order to investigate the feasibility of the proposed measure, as well as to perform the training of the classifier, walking tests were performed involving 10 healthy control (HC) subjects, and 17 patients with NDDs (3 with multiple sclerosis, 6 with polyneuropathy, 8 with Parkinson' diseases). The hip and knee joint angle trajectories recorded with IMUs were firstly segmented into individual cycles as the proposed novel measure is based on calculating of the difference in shapes of two gait cycles trajectories. Four functions (mean subtraction, mean root-mean-square-deviation, mean dynamic time warping and maximum cross-correlation), were defined and applied to calculate this difference. Two types of features, gait stability and gait uniformity features were extracted using defined functions. 70% of the gait cycles of the recorded hip and knee trajectories of all 27 subjects were utilized for the training and validating of a SVM binary classifier, which distinguishes impaired gait from the healthy gait. During the test phase, the features of the remaining 30% of the gait cycles served as input to the SVM classifier, and the proposed novel measure for the gait quality monitoring is calculated as the percentage of gait cycles classified as impaired gait cycles. The measure is a probabilistic value indicating the distance of the gait quality to the normal (healthy) range, where higher value represents higher impairment (worse quality) of gait.

Results

In addition to the test involving 17 NDD patients, where introduced classifier gave very promising results (Accuracy = 98%), the proposed gait quality measure was also validated in a study involving a patient with Hereditary Spastic Paraplegia (HSP) who was investigated for one year before and during stochastic resonance therapy (SRT). The gait parameters of the patient were recorded and processed so to calculate proposed gait quality measure for 4 therapy phases: just before the start of the SRT (Pre), 2, 4 and 12 months after the start of the SRT. The results indicated significant improvement in gait quality after 2 months of therapy compared to Pre, and steadier improvement afterwards. This result is in line with the results of the performed standard clinical tests (10m test and TUG). However, it is important to note that the goal of this study was not to evaluate the effectiveness of SRT by gait analysis. The goal was to demonstrate the effectiveness of the proposed measure in gait monitoring and the study with HSP performed over 12 months enabled this long-term monitoring.

Conclusion

In this paper, a novel measure to quantify the gait quality during the therapy of patients with gait impairments was proposed, with which the changes in gait can be quantified by a single numeric value reflecting the degree of impairment. The effectiveness of the measure for long-term monitoring of gait quality was validated in a study involving a HSP patient who was under SRT for 12 months. The achieved results are promising, which indicates that the proposed measure could be used as an effective way for long-term monitoring of gait performances.

FES-based arm weight relief: First investigations in stroke patients

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Introduction

Stroke patients often suffer from a reduced volitional activity in the shoulder deltoid-muscle that may hinder functional movements as the arm elevation is insufficient. To support such small voluntary forces, Functional Electrical Stimulation (FES) can be applied to the corresponding muscle for gaining additional force. Previous elaborated approaches employ Electromyography-measurements (EMG) to detect the volitional activity to control the intensity of FES. However due to the low signal-to-noise ratio when obtaining EMG during active FES, a precise user-control is difficult to achieve. The aim of this work is to develop a neuro-prosthesis relying on angular measurements for detecting the user's intent and to test its feasibility in end users with stroke. Hence, we developed a neuro-prosthesis only relying on angular measurements to detect the user's intention.

Methods

Feedback-controlled FES is applied to the frontal shoulder deltoid muscle, while the shoulder abduction angle is measured by an Inertial Measurement Unit (IMU). Additionally, measurements of the stimulation evoked EMG (eEMG) are used to compensate for the effects of muscle fatigue by an underlying feedback loop that realizes a desired muscle recruitment. The effectiveness of this approach has been shown in a pilot study in previous research. Based on the measured shoulder elevation angle, an FES-induced muscle recruitment is generated that yields a pre-specified percentage (a constant support factor) of this angle – yielding an arm weight relief. With that, less residual voluntary activity is required to perform functional tasks. An analytical analysis proves the asymptotic stability of the positive-feedback loop for support factors less than 100%. A fully automated calibration procedure adapts the parameters of the recruitment controller and the weight relief to the individual user. The support factor may be adjusted by the user or caregiver to meet the users' requirements regarding the available volitional activity.

Results

The neuro-prosthesis was tested in two acute stroke patients P1 and P2. Patient P1 suffered from a strong paresis. Without support, he could only elevate his arm by 6°. When we activated FES, an elevation by 25° was possible in case of the maximally possible support factor (100%). In case of patient P2, a maximal volitional elevation of 35° was observed when no FES-support was present. The device was tested for different support factors. For a range of 60% to 80%, a restoration of the complete range of motion (90° and more) was possible. In all cases, smooth arm abduction movements were achieved.

Conclusion

The preliminary results from this single case series indicate the feasibility of the arm weight relief neuroprosthesis to increase shoulder abduction in case of a limited range of motion due to paralysis. In this approach, the user can volitionally control his arm abduction. For patients suffering from a strong paralysis, as demonstrated by P1, the control is possible but less precise. We expect that a more precise measurement of the abduction angle solves the remaining issue. In case of a slight paresis (P2), the system performed as expected and a restoration of functional movements was possible. For both patients, the steps required to apply the system including electrode placement and calibration did not exceed more than 15 minutes, though there is still room for improvement. The proposed neuroprosthesis is intended for trial-based training for motor re-learning in therapy as well as for daily-live support at home in form of a portable device.

Though the system currently supports only the elevation, volitional horizontal shoulder movements are possible in a feasible range. An extension also stimulating the medial deltoid is foreseen whereby crosstalk effects in the eEMG are already considered in recent versions of the recruitment control strategy.

Towards a High Motor-Precision Neuroprosthesis by Recruitment-Controlled Antagonistic Muscle Co-activation Strategies

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Introduction

The motor precision of today's neuroprosthetic devices that use artificial generation of limb motion by Functional Electrical Stimulation (FES) is generally low. We investigate the adoption of natural co-activation strategies as present in antagonistic muscle pairs aiming to improve motor precision produced by FES. We present an open-loop knee joint-angle control system to test four different variants of co-activation. An underlying feedback of the stimulation evoked EMG (eEMG) – presented in earlier research – is used to realize a desired level of muscle recruitment also in the presence of muscle fatigue. This allows a reliable generation of co-activation levels without the need of re-tuning controller parameters. By a control test in one healthy subject, we evaluated the obtained smoothness of joint motion. Further, we demonstrated the modulation of joint stiffness for different levels of co-activation in a pendulum test.

Methods

FES is applied to the quadriceps (channel A) and the hamstring muscle (channel B), and EMG is obtained for each muscle. The stimulation intensity is controlled by two separated recruitment-controllers. The knee-joint angle is measured by means of an inertial sensor. An open-loop control strategy is implemented that distributes a given angle reference based on a switching strategy (switching occurs when the reference angle passes 0°) to both desired recruitment levels to realize joint-motion. The aim is to achieve a motion that transitions steadily through the switching of the activation between hamstrings and the quadriceps. Therefore, four different strategies to realize co-activations are additionally investigated: (1) Simultaneous muscle activation yielding a constant co-activation level, (2) Modulation of the co-activation based on the angle-reference, wherein (2a) both agonist and antagonist are increasingly activated as the angle-reference increases. The antagonist with a smaller slope, however. In (2b) co-activation is linearly increased as the angle-reference approaches zero within a band between -10° and 10° around the zero angle. Option (2c) combines (2a) and (2b). A 5th option (3) does not involve co-activation.

Results

The control system was applied to a healthy subject seated on an elevated surface with the leg free to swing and asked to relax the whole time. In a first test, the subject's leg is flexed to approximately 55° and a constant co-activation level (strategy (1)) was realized, whereby the angle reference was zero. Then the leg is released and the swinging process is recorded. This was done for multiple levels of co-activation. The duration of the swinging process monotonically decreased from 2.7s to 0.5s as the level of co-activation increased. In the next test, a piecewise linear movement in a range from ϑ_{low} to ϑ_{high} should be realized. For this, we generated the angle-reference by means of a hysteresis controller that alternates between linearly inc.-/decreasing angle-reference using a given slope of 72°/s. The slope changes its direction when the measured knee angle crosses the thresholds $\vartheta_{low} = -7°$ and $\vartheta_{high} = 17°$. To evaluate the smoothness during the switching of activation, a linear model was fitted to the measured angles in a range between -5° and 5°. The RMS-error between this model and the measured data then yields the degree of smoothness J. Variants (3) ($J = 2.62°$) and (2a) ($J = 2.94°$) resulted in jerky movements, especially when switching between muscles occurred. Using constant co-activation (1), the smoothness improved strongly ($J = 1.11°$). Even better results were obtained for (2b) wherein co-activation is only induced when switching occurs ($J = 0.51°$). Expectations on a triangular movement were mostly fulfilled in (2b) and (2c).

Conclusion

The motion smoothness could be significantly improved compared to no co-activation. We expect the results to also apply to e.g. the control of the elbow-joint angle and the finger and wrist extension/flexion. These investigations aim as a basis for future neuroprostheses to restore paralyzed functions.

Predicting human lifting motions using optimal control

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Introduction

Wearable robotic suits are being designed for rehabilitation and the prevention of injury. One of the challenges that designers face is the lack of tools to predict how the human user will move with the suit. Optimization can be used to predict human motion given a sufficiently accurate rigid-body model and cost function [1].

While musculoskeletal modelling has been an active area of research for nearly 40 years, the cost functions used to predict human movement have not been studied in the same depth. In this work we focus on how the cost function affects a stooping motion when picking up a 15 kg box (with handles) off the ground. We are examining a stoop because it is associated with low-back injury [2], and is performed by millions of agricultural workers [3].

Methods

We model the human body as a planar floating-base rigid-body mechanism with 16 segments and a total of 18 degrees-of-freedom. The model is actuated by set of muscular-torque-generators which have been fitted to experimental data to mimic the characteristics and strengths of various joints of the body. We use the the open-source software Rigid-Body Dynamics Library (RBDL) written by Martin Felis to model the dynamics of the body.

We consider two different functions to define the cost of the movement: muscle-activation squared, and normalized muscle-torque squared. Muscle activation is a scalar quantity between 0 and 1 that represents the percentage of a muscle's fibres that have been chemically activated to generate tension. Cost functions based on muscle activation have been used to solve a variety of problems in the literature ranging from the muscle force distribution problem to the prediction of human walking. Though cost functions based on muscle torque are not commonly used, the work of Farley and Taylor [4] provides some experimental evidence to support their use.

We use the multiple shooting method described by Bock and Pitt [5] and implemented in the software MUSCOD-II by Leineweber et al. [6] to solve for stoop motions that minimize activation-squared and normalized torque-squared cost functions. Next we compare the lumbar motions and net torques to those of a single experimental subject. The motions of the experimental subject were recorded using OptoTrack IRED marker clusters attached to 14 body segments. In addition, we also compare our results to the peak lumbar flexion angles and extension torques from 10 subjects lifting a 10.5 kg box from a height of 0.5m reported by Kingma et al. [7].

Results

The peak lumbar flexion angle of both the activation-squared (41°) and the torque-squared solution (39°) were different from our experimental subject (13°), but similar to the co-hort reported by Kingma et al. (39° ±12.5°). The peak lumbar torque of the torque-squared solution (172 Nm) is similar to the human subject (200 Nm) and to the co-hort reported by Kingma et al. (199±12 Nm). In contrast, the activation-squared solution exhibits a peak lumbar torque (142 Nm) that is lower than both the experimental data and the torque-squared solution.

Conclusion

Despite its lack of use in the literature, the torque-squared cost function produced a more life-like prediction than the activation-squared cost function. This work highlights need improving the cost functions of human movement so that more accurate motion predictions can be made in the future.

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Conventional and Microprocessor-Controlled KAFOs: Comparative Evaluation of Functionality Based on Biomechanical, Metabolic and Safety Parameters

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Introduction

In the past, patients with severe muscle weakness and paralysis in their lower limbs were not able to flex the knee during weight bearing with a conventional KAFO (cKAFO; KAFO: Knee Ankle Foot Orthosis). The most important KAFO principles are locked orthoses (lKAFO) and stance control orthoses (SCO). The function of knee flexion under weight bearing is now allowed for the first time by a microprocessor stance and swing control orthosis (C-Brace). The resulting patient benefits provided by this orthosis were objectified in a biomechanical investigation [1]. Besides the biomechanical functionalities, the metabolic energy consumption and the safety level that can be objectified with the different KAFO principles are of high value to the patient. This presentation reports all results comparing the parameters for the C-Brace orthosis and the cKAFOs.

Methods

Six patients participated (56±13y, 70±12kg, 164±11cm) who had been using cKAFOs for at least 2 years (4xSCO, 2x-lKAFO). After the biomechanical tests with the cKAFO (level walking, descending ramps and stairs), the subjects were fitted with the C-Brace followed by an adaptation period of 12 weeks on average. After this period, the biomechanical tests were repeated with the C-Brace. For the measurements, 2 force plates (KISTLER, Wintherthur, CH), coupled with a kinematic measuring system (12 BONITA cams, VICON, Oxford, GB), were used (assessment parameters: ground reaction forces, joint angles and joint moments). The metabolic parameters were measured during a 6-minute treadmill test at self-selected velocity (METAMAX3B, CORTEX, Leipzig, Germany). The safety of the KAFO systems was evaluated based on a study design from prosthetics [2].

Results

For level walking, the mean time-distance-parameters do not show any significant differences between cKAFOs and C-Brace. The mean swing phase flexion angle was 66.6° with the C-Brace orthosis, and 74.0° with the 4 SCOs (significant difference, $p \leq 0.05$). The external joint moments of the sound side that are important parameters for the evaluation of the load acting on the locomotor system [3], do not show any significant differences between SCO and C-Brace. Comparing, however, the LKAFO with the C-Brace, these moments are significantly reduced with the new system.
With the cKAFOs, 4 of 6 patients were able to descend ramps step over step, with the C-Brace each patient could perform this motion pattern. For all patients, continuous knee flexion was measured under weight bearing with C-Brace (mean maximum flexion 65°). With the cKAFO, none of the patients was able to descend stairs step over step, with the C-Brace this was allowed for each patient. Similar to the results on the ramp, continuous knee flexion under weight bearing was measured without exception (mean maximum flexion: 70°).
Oxygen cost with the C-Brace was reduced on average by 8% in the SCO patients (0.198 vs. 0.216 ml/kg*m) and by 4 and 10%, respectively, in the 2 LKAFO patients. During testing of safety (SCO vs. C-Brace), patients were at risk of falling in 61% of all trials with the SCO, but only 7% of all trials with the C-Brace.

Conclusion

Due to the possibility of safe damped knee flexion during weight-bearing, the C-Brace allows the patients to descend ramps and stairs nearly naturally. The significantly higher safety level of the C-Brace encourages the patient to use the functionality of this new system with a high degree of confidence without requiring any specific motor control of the orthosis. Despite a higher mass this effect results in a reduction of the metabolic energy consumption.

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Adaptive ankle control – Properties of an innovative system for foot stabilisation

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Introduction

Common systems for foot stabilization offer a protection effect (brace / foot orthosis) or high flexibility (bandages) but never combine both. An innovative foot stabilization system based on dilatant fluids provides flexibility during slow movements and high protection from ankle sprain injury during fast movements. Therefore, it is adjusted adaptive and without any sensors to patient's movements by the ankle supination velocity. The combination of high range of motion and high protection provides different advantages. Due to the possibility of unrestricted movements during therapeutic use the risk of muscular dystrophy and degeneration of sensorial motor skills can be reduced. Furthermore the high range of motion enables a prophylactic use for every sort of sports, leading to an injury reduction and lower costs for the health system.

The ankle supination velocity-dependent performance of this innovative systems for foot stabilization and the comparison to common systems has been characterized in a testing bench.

Methods

The testing device consists of an ankle model (AM), clamped into a speed controlled tensile test machine. This AM includes the upper and lower ankle anatomical axes thus enabling plantar flexion, dorsal extension, inversion, and supination of the foot. Nevertheless, the main focus of this research lies on supination movements. During supination motions the angular position and velocity of the upper and lower ankle and the resistance moments measured by a force sensor are quantified.

In this way, common systems like bandages and orthosis and the innovative system for foot stabilization have been compared. A standardized supination motion up to 45° with variable speed was simulated for all products tested, starting with an ankle speed of 7°/s up to 360°/s. Afterwards the measured resistance moments in respect to the supination speed were analyzed.

Results

The results for the different foot stabilization systems showed the following behavior:

1. The bandage resistance moment (4,9Nm) is significantly lower compared to a foot orthosis (13Nm).
2. Both bandages and orthosis show a constant resistance moment irrespective of the supination velocity. The specific resistance moments remain at the same level during both low and high supination speed.
3. During low supination speed the innovative foot stabilization system shows a low resistance moment, comparable to the level of bandages. During high speed (beginning at 36°/s up to 80°/s) the performance increases rapidly up to the level of orthosis resistance moment, thus showing a velocity depending performance.

Conclusion

The results confirm the adaptive, velocity depending performance of the innovative foot stabilization system. It provides low resistance moments at slow physiological ankle supinations, offering the same flexibility as bandages. On the other hand, it develops a rapid protection effect during fast non-physiological motions by providing high resistance moments comparable to the measured orthosis.

In general, there is a lack of data concerning the resistance moment of common foot stabilization systems and the AM simulates the foot ankle with restrictions (for example skin friction is not modeled). Despite those differences to real ankle supinations, relative comparisons within the measurements are possible.

Upper limb virtual reality training provides increased activity compared with conventional training for severely affected patients in the subacute phase after stroke

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Introduction

Virtual reality (VR) training is thought to improve upper limb (UL) motor function after stroke when utilizing intensive training with many repetitions. The purpose of this study was to compare intensity and content of a VR training intervention to a conventional task-oriented intervention (CT).

Methods

Cross-sectional analysis as part of the virtual reality training for upper extremity in subacute stroke (VIRTUES) trial (trial registration: ClinicalTrials.gov NCT02079103). We analyzed a random sample of 50 video recordings of patients with a broad range of UL motor impairments (mean age 61y +/-14, 22 women). The patients were randomized to either VR or CT and stratified according to severity of paresis. A standardized scoring form was used to analyze intensity, i.e. active use of the affected UL expressed in percentage of total time, total active time and total duration of a training session in minutes, content of training and feedback. Two raters collected data independently, interrater reliability was examined with ICC statistics with excellent agreement ($ICC_{agreement}$ = .98). We fitted an unadjusted linear regression model with the predictors VR and severe paresis one at a time as well as an adjusted model including both predictors and their interaction.

Results

Patients in the VR group spent significantly more time actively practicing with an activity rate of 77.6 (8.9) % than patients in the CT group 67.3 (13.9) % (p=0.003). This difference was attributed to the subgroup of patients with severe paresis. While in VR severely impaired patients spent 80.2 (4.4) % of the session time actively, they reached 61.6 (12.1) % in CT (p=0.005). VR and CT also differed in terms of tasks and feedback provided.

Conclusion

Our results indicate that patients with severely impaired UL motor function spent more time actively in VR training, which may influence recovery. The upcoming results of the VIRTUES trial will show whether this is related to better outcome of virtual reality compared to conventional training.

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Evaluation of consumer grade Time of Flight cameras for marker-less motion capture

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Introduction

Due to recent advancements in medicine, the number of elderly is increasing and is expected to increase exponentially in the near future (United Nations, Department of Economic and Social Affairs, Population Division, 2015). This poses a challenge for our society in a number of ways; healthcare for the elderly to enable them to live independently; high quality and long term care facilities need to be ensured; training for the family members and/or caretakers who are looking after the elderly. Due to these challenges owing to the shifting demographic, there is a dire need for more skilled caregivers than ever before. This poses a significant challenge on public health as inadequately trained caregivers face health issues themselves. Musculoskeletal disorders (MSD) such as lower back pain is one of the most frequent hazards for caregivers. To train correct ergonomics to caregivers, a large amount of resources is required. This can be minimised by using a virtual training system capable of tracking their motion and monitoring correct ergonomics.

Conventionally, human motion is tracked using marker based optical systems. Such systems are relatively expensive, require a dedicated area and a special suit for the user which can prove to be inconvenient and intrusive in some situations. An alternative is to use Time-of-flight (ToF) cameras to provide marker-less motion capture. ToF cameras calculate the distance value for each pixel by emitting infrared radiation and measuring the time for the signal to be reflected back. They provide monocular disparity free 3D data, avoiding complexities associated with stereo imaging. ToF technique is also more robust to ambient conditions as compared to other techniques such as structured light (Langmann, et al., 2012). However, there are some inherent problems associated with using infrared radiation like dependency on material, saturation in direct sunlight etc. (Fürsattel, et al., 2016) Current methods to capture motion also suffer from occlusion limiting their capability of pose estimation. A multi view setup helps to reduce occlusion (Gao, et al., 2015). However, using multiple ToF cameras simultaneously with overlapping fields of view can be a challenge in itself.

Methods

The release of consumer grade Microsoft Kinect v2 and Pmdtec Picoflexx have broadened the scope of affordable motion capture for domestic purposes. Nonetheless, their capabilities rely on a number of factors especially if the operation is in sunlight, reflectivity of the material measured, interference with other modulated infrared radiation sources, initial time needed for warming up the IR emitters and accuracy of the camera. These consumer grade cameras are becoming widely available and provide cheaper alternatives to using industrial grade ToF cameras. Both of these cameras have different characteristics such as size, outdoor performance etc. It is important to compare and characterize the two consumer products through a series of different experiments.

The experiments were conducted in a confined space of 4m by 2m which was completely covered in light absorbing Duvetyne fabric to eliminate unwanted reflections and a plain white target was mounted on a motorized linear stage for accurate actuation in the Z axis. To measure the warm up time of each camera, the target and a ROI of 10 pixels by 10 pixels at the centre of the target was measured at 2 m for 60 minutes and change in measured distance in the average of the ROI noted at 10 s intervals. It was made sure that the cameras have been unplugged at least an hour prior to the experiments to let them cool down completely. To measure the accuracy of the cameras, the target measured with varying distances at 10 cm intervals. The same ROI was recorded and its average noted. The measured value was compared to the actual ground truth distance. Different materials with varying surfaces and reflectivity were also placed at 2 m and the error in measured distances for each material noted.

In order to minimize interference, the Kinect v2 switches between modulation frequencies randomly. However, if the frequencies match, interference can occur and change the measured distance by the camera. In order to measure the extent of interference, the target was measured at 2 m by the two cameras simultaneously directly facing it for 2 hours.

Results

It has been noted that the Kinect v2 sensor takes about 20 minutes to warm up to a constant temperature and then the active cooling turns on to maintain the temperature. The Picoflexx, due to the smaller size of the emitter, warms up quickly and doesn't need active cooling, it dissipates heat through convection. The accuracy of both systems is under ±5mm. Very dull and very bright objects prove to be problematic and are not detected by any of the cameras. Currently, on-going research is being conducted to determine the extent and effect of interference.

Conclusion

To provide affordable marker-less motion capture, use of consumer grade ToF cameras is becoming more significant. However, they have some serious limitations which have to be accounted for depending on the application. It was shown that Microsoft Kinect v2 and Pmdtec Picoflexx provide a good accuracy. They require some time to warm up to give reliable results. Their use also highly depends on the type of material being measured. To reduce occlusion in human motion capture, multi-view setup may be required. This can also cause interference between multiple cameras while operating simultaneously and might have to be time multiplexed, depending on the application.

A Test Rig for Investigating Manual Wheelchair Propulsion Devices

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Introduction

The wheelchair is one of the most commonly used assistive devices for enhancing the mobility of people with disabilities, and is used for ambulation by a high population of lower-limb disabled persons.

According to the World Health Organization an estimated 1% of the world's population require the use of a wheelchair. [1]

Ninety percent of all wheelchairs are propelled manually by using the arms to apply force to the push rim. Manual wheelchair propulsion is a highly repetitive movement that frequently causes musculoskeletal disorders and upper limb pain due to high loads. Furthermore the stroke in manual wheelchair propulsion with a push rim is discontinuous and characterized by low mechanical efficiency, typically below 11%. [2]

To investigate and compare different wheelchair propulsion devices and their efficiency and loads on musculoskeletal structures, reproducible and comparable measurements on wheelchair propulsion are needed.

The main goal of this study was to develop a wheelchair based test rig on which alternate hand driven mechanisms for wheelchair propulsion can easily be mounted and propulsion efficiency as well as loads on the musculoskeletal structure analysed and compared.

Methods

A standard wheelchair represents the starting point for the development of the test rig. Main focus was set to realistic imitation of propulsion phase, quick change of attached equipment from left to right side (less than 10 minutes) and development of an easy to use graphical user interface (GUI).

To simulate real propulsion conditions, a resistance that varies with translational speed was generated. In literature the total resistance power of a wheel is defined as the sum of resistances due to translation, rotation, inclination, air and rolling. A controlled brushless motor combined with a fly wheel mounted under the wheelchair was used to simulate the acceleration and deceleration phases as well as the resistance power. For a slip free power transmission to the wheels and front connection points, timing belts were used. When the user starts propelling the wheelchair by using the push rim or an attached front drive, the motor generates a resistance torque that is transmitted via timing belts to the push rim wheels and front drive pulleys. A motor integrated hall sensor is used to control the motor as well as to provide important speed information. The software developed in LabView® enables both setting parameters and controlling the motor. The user can set velocity, inclination and floor condition profiles for every task. In the main window of the GUI, the actual speed and the target speed are shown in a huge line graph. Measurements with analogous speed profiles can be done by aligning actual speed to target speed as good as possible during propulsion. To verify realistic functionality of the test rig, a SmartWheel® was mounted on the wheelchair and the generated forces during push rim propulsion on the test rig were compared to those recorded when the wheelchair was detached from the test rig and used as a standard mobile wheelchair.

A fixed time span of 1.5 seconds between the single propulsion strokes was set. And three healthy subjects performed 10 propulsion cycles in both modes. The measured data was normalized and compared.

Results

The trajectory of the forces measured during propulsion on the test rig is close to the trajectory measured on the mobile wheelchair, differences are within the range of the standard deviation. The subjects rated subjectively that the test rig provides conditions very close to reality. Changing propulsion devices from left to right side on the test rig can be done in less than 5 minutes.

Conclusion and Outlook

A wheelchair based test rig for manual wheelchair propulsion was developed, which allows easy and reproducible testing of alternative manual propulsion devices. The use of timing belts for the transmission of resistance torques instead of friction rolls allows slip-less measurements with different propulsion methods. Both the various mounting possibilities for hand propelling devices as well as its connectivity have been proved useful. The multiple adjustment possibilities give this test rig a wide range of use. In accordance with the first tests, the test rig may be a useful device for investigating upper limb load and activities during manual wheelchair propulsion. In the next step, the test rig will be combined with a real time force-torque measuring handle to extend the functionality of the whole system.

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The Biomechanical Need of the Proximal Brim in Transfermoral Prosthetic Sockets

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Introduction

There are different prosthetic socket technologies for the treatment of transfemoral amputees. Ischium containment socket technologies have established in the past. They differ from other technologies in shape and functionality (Sabolich, Ortiz, Schuch). The main difference is to be found in the proximal functional area that is responsible in different proportions for the force transmission between the residual limb and the bony pelvis structures. Socket technologies without force transmission in the pelvic region are available as well (brimless sockets).
Within the scope of this biomechanical study, a study design has been developed to investigate force transmission principles by main functional elements of a transfemoral prosthetic socket. The study aims at further increasing the understanding of force transmission between residual limb and prosthetic socket.

Methods

To record the forces in the four main socket areas (area of ischium containment, lateral support, frontal support, volume and control area), the sockets are segmented according to these areas and implemented in a CFK frame. Between frame and socket segments, load sensors are installed. They are able to record three forces in the corresponding segments and their centres of pressure within a cartesian coordinate system. Using a self-developed data transmission path, the measuring data are transferred via a mobile wireless LAN system to a central PC and triggered synchronically to a stationary gait analysis system (Kistler, Vicon).
Loading between the residual limb and three different sockets (CAT-CAM, MAS, brimless socket) was measured with 6 transfemoral amputees in the following situations: standing with different socket adduction and flexion angles, level walking, descending stairs and ramps. For the measurements in standing, the measured socket is tightly installed on a stationary fixture and brought into the different test positions by means of a spherical sliding adapter. For the measurements during movement, a trial prosthesis with a prosthetic knee joint and a prosthetic foot is mounted by analogy with the everyday prosthesis.

Results

The results demonstrate that the principles of force transmission between a CAT-CAM and MAS socket do not significantly differ from each other - neither in standing position nor during walking. With both socket types, a high degree of axial forces is transferred by the medially located containment area. Furthermore it becomes obvious that the contribution of the containment section for frontal and sagittal plane stabilization between residual limb and socket during the stance phase is of very high importance. With the brimless socket that does not contact the pelvis, differences can be identified, however. They are to be found in the position of the total force running through the socket leading to the conclusion that the force transmission principles are different compared to an ischial containment socket. Additionally, the stabilization effect between residual limb and brimless socket in both sagittal and frontal plane seems to be reduced.

Conclusion

In the literature, the force transmission principles of femoral socket technologies have been discussed exclusively on the basis of fitting experiences (Sabolich, Ortiz, Schuch). Theoretical models such as the so-called hydrostatical principle have been used. They have assumed that - also with ischial containment total contact sockets - an axial force can only be transferred by the soft tissue cover of the residual limb. However, clinical observations have not always confirmed this approach. Overloading is often caused in residual limb areas that according to the socket technology used should not transfer any forces. The method described in this study allows for the first time to objectify by comparison which socket areas are involved in force transmission and to what extent.

CYBERLEGs Beta-Prosthesis: Testing and Cybathlon

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Introduction

The CYBERLEGs Beta-Prosthesis is a new transfemoral prosthesis with two active degrees of freedom in the knee and the ankle designed primarily to help those with limited ambulation ability with standard prostheses due to weakness from advanced age or complicating illness. Although the device has two powered joints, a MACCEPA based ankle mechanism with a parallel spring mechanism and a series elastic knee mechanism paired with a parallel spring mechanism that engages using a thread based locking mechanism, it is designed to allow a high level of passive action during the gait cycle through the use of passive components that are inserted or taken out of the gait cycle by locking mechanisms. Through the use of these passive energy storage components, it is possible to achieve a fluid motion while, with simple control, remaining relatively energy efficient. The prosthesis is capable of providing the full ankle and knee torques during walking, as well as a large percentage of the torque required for normal sit to stand and stair climbing.

Methods

The CYBERLEGs Beta-Prosthesis was tested using two different control systems. The first was the CYBERLEGs system which contained a finite state machine triggered through a combination of 7 IMUs and pressure sensitive insoles. The second system was a finite state machine driven by a simple 3 DOF rate gyro, an augmented and modified phase angle system using elements of the system developed by SpringActive, and a touch screen for determining action transitions.

Testing of the device has been performed on patients at the Don Gnocchi Foundation, Italy, as well as in Brussels and used in competition during the first Cybathlon held in Zurich, Switzerland in October 2016. The CYBERLEGs Beta-Prosthesis system was tested in Italy on four healthy, elderly (>50 years), male individuals under a variety of conditions including level ground walking in a catwalk, treadmill walking, sit to stand and stand to sit, and stair assist (step by step) and used the first control system. For the Cybathlon competition, the tests were performed with a fifth healthy, elderly and male amputee and also included slope walking and decent, stair climbing (step over step) with a hand rail, and hurdle navigation. These experiments used the simplified control system and intention detection system.

Results

All but one walker was able to perform the tasks as described and reported benefit from the prosthesis particularly in the sit to stand and stand to sit operations. The prosthesis was capable of climbing stairs step over step with the use of the handrail, with limited training of the pilot. This allowed the amputee to surpass the capabilities of his habitual prosthesis for this task. When the control parameters are well tuned to the needs of a specific amputee, the walking gait is stable and fluid, yet still requires a high amount of cognitive effort from the amputee compared to the habitual prosthesis.

Conclusion

The CYBERLEGs Beta-Prosthesis is capable of providing a significant amount of torque to the knee and ankle while walking and actively add energy enabling low activity level amputees to perform tasks they would not be able to perform with passive devices. Due to design decisions, the prosthesis is limited in joint velocity because the device was intended for individuals with poor locomotor ability and condition. Therefore it is not optimized to be used with high-functioning amputees, but regardless the device performed well at low velocities and enables the users to perform tasks they would otherwise not be able to perform. Although the performance during the Cybathlon did not compare to the other top of the market designs when looking at the time it takes to fulfil the tasks, the device performed all of the tasks that were deemed possible by the start of the competition, moreover tasks the amputee would not have been able to perform with a passive device and the same limited training. Future studies will focus on decreasing weight, increasing reliability, incorporating better control, and increasing the velocity of the device.

Gait Simulator for Lower Limb Prosthesis: Shock Absorber for Modelling Soft Tissue Damping

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Introduction

The gait simulator, a test device for lower limb exoprostheses developed at the Department of Medical Engineering of the TU Berlin, allows different complex prostheses testing. The device can apply a wide range of loads to prostheses to simulate different gait cycles and other scenarios without involving a subject. However, results of comparative measurements with microprocessor controlled knee joints with the gait simulator showed possibilities for improvement. Usually prostheses are connected through a socket to the user. The connection of the prostheses to the device is rigid. This results in a peak of sagittal moment at swing extension stop and leads to an oscillation and decreasing control quality. To fulfill the demands of comparative measurements with high gait velocity the device requires a new appropriate stump-socket-interface. Therefore a shock absorber with different adjustments was developed. It simulates a part of the interaction between the socket and the stump to reduce peaks in sagittal moment.

Methods

Regarding to literature, at late swing phase the socket rotates towards the hip joint in sagittal plane, while the knee extends completely. This reduces the sagittal extension moment through lowering brake acceleration. Therefore the shock absorber is a joint with a rotational degree of freedom in the sagittal plane above the knee joint. Upon surpassing a certain moment threshold, the shock absorber activates, dissipating energy. This moment threshold can be set between 0 and 50Nm through the use of tension springs. Pressure springs with a variable lever allow for an adjustable rotational stiffness in a range between 0 and 2000Nm/rad. A part of the kinetic energy generated through rotation is dissipated through a damper which can be adjusted between 0 and 50Nms/rad.

Results

The first measurements show a reduction of the sagittal moment peak by 65% at swing extension stop. This leads to an increased control quality and improvements in simulation. Additionally, the variability of sagittal moments is decreased for more realistic testing conditions.

Conclusion

Instead of a rigid prostheses connection to the gait simulator, an appropriate stump-socket-interface is needed. A shock absorber with different dynamic adjustments grants a new degree of freedom in the sagittal plane above the knee joint. Peaks in sagittal moment are reduced which leads to a more stable control and wider application possibilities of the test device.

Development of a haptic system for the digitization of body parts

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Introduction

Orthopaedics is a craft that highly depends on manual processes and the experience of individuals. It has been difficult to standardize the care process due to the high individuality of each patient. With the development of new technologies approaches to regularize and automatize these processes are in the focus of rehabilitation research. In order to optimize the casting process of body parts, a system has been developed that allows the orthopaedic technician to digitize a body part by tactually scanning the surface and localizing underlying anatomical structures.

Methods

The developed system is based on the technology of electromagnetic tracking systems. The hardware components and sensors are part of the Aurora product line manufactured by Northern Digital. The sensors are worn on the fingertips encased in silicone. A software to process and visualize data and lead through the scanning process has been implemented in Matlab. To validate the system, accuracy measurements have been performed and the system's usability has been evaluated by orthopaedic technicians in an application oriented scenario. The tactile measurement accuracy was examined in a test scenario with ten subjects: With an instrumented index finger eight different geometric objects hidden beneath a 2cm layer of foam were palpated five times each. Surface scans of a soft foam dummy of a transfemoral stump were tactually recorded and compared to an optical scan of the same model.

Results

For the tactile measurement of hidden objects an accuracy of 2.85 ± 1.42 mm over all subjects and trials was achieved. Potential for optimization of the location of the sensor on the finger has since been identified and more accurate results are expected with an optimized design. The comparison of haptic surface scans with an optical scan shows good congruence if the scans have been done with care. The orthopaedic technicians have given an overall positive feedback for the system and the implemented scanning process.

Conclusion

The results show a good accuracy and repeatability of measurements and promise a significant improvement of the manual casting process. Since the workflow is similar to the standard casting process and the orthopaedic technician is assisted rather than replaced by the system, a high acceptance is expected. The interviews with the consulted orthopaedic technicians support this supposition.

Bending and torsional moments acting on prosthetic feet – a pilot study

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Introduction

Gait analysis of patients with lower leg amputations is often performed by the comparison of prosthetic and contralateral sides using kinematic and kinetic measurement devices like camera systems and force platforms. This study used a new insole measurement system (vebitoSCIENCE, vebitosolution GmbH, Steinfurt, Germany), which provides bending and torsional moments acting under the foot in shoes. The insole contains 5 measuring locations on a forked carrier out of stainless steel. Because of the shape it is possible to examine the medial and lateral forefoot separately. In comparison to pressure measurement it is possible to measure multidimensional with the vebito system.

In this study the bending and torsional moments acting on both sides when wearing prosthetic feet are recorded and evaluated. Additionally, this paper focuses on the effect of the same foot used by different subjects. The aim was to find out, if the results can be of benefit for e.g. a prosthetist concerning the choice and adjustment of prosthetic feet for patients.

Methods

Six subjects (4 f, 60 ± 10 years) participated in the pilot study. They were able to walk the distance of 10 m in a self-selected speed. During the measurements the subjects wore a neutral shoe (Adidas® Samba). Two measurements were recorded. In the first trial the subjects used their own prosthetic foot, in the second one they received a new foot, which they have never worn before. The new foot was chosen and adapted by an experienced prosthetist (UKM ProTec Orthopädische Werkstätten GmbH, Münster, Germany) considering the activity level of each subject.

The vebitoSCIENCE insole (125Hz, Bluetooth data transmission) was used to obtain bending and torsional moments at the heel, MTP I, MTP V, DIP I, and DIP V. Data analysis considered 7-8 strides out of every measurement. For these strides the bending and torsional moments were normalized to 100% gait cycle (GC) and averaged. The results presented in this paper deal exclusively with the heel with focus on (i) a description of the general shape of the bending moment curves and (ii) the ranges of both bending and torsional moments.

Results

The curves of the bending moment show similar shapes for all subjects, both feet and both sides. After initial ground contact the bending moment increases strongly up to 5-10% of GC. At 70% of GC the data reaches the same level compared to the initial ground contact and then remains almost constant during the swing phase. The torsional moments mostly also show these shapes, except the maximum occurs a little later, at 10-20% of GC. In general, the prosthetic feet show higher maxima compared to the contralateral side.

The bending and torsional moments of one subject are very similar at both sides, independent from the two different prosthetic feet. The bending moment ranges within this subject are 88 and 105 Nmm on the contralateral side, whereas the prosthetic side shows ranges of 400 and 459 Nmm. The torsional moments' ranges on the contralateral side are 135 and 145 Nmm and on the prosthetic side 228 and 276 Nmm. The moments of all 6 subjects indicate more similarities concerning shape and range on the contralateral side. Moreover in most cases it is noticeable which 2 curves belong to 1 subject, when comparing all measurements. On the prosthetic side there is more deviation. This appears mainly in the range, which differs from 33 to 462 Nmm (bending) and from 31 to 438 Nmm (torsion).

One type of prosthetic feet (Quantum, Ortho Reha Neuhof) was worn by 3 subjects during the second measurement. The bending moment curves of the prosthetic side show a very similar trend for all these subjects. However, one curve reveals a maximum which is about 50% lower compared to the other 2 subjects. In general the corresponding data of the contralateral side have lower maxima and less mean variation compared to the prosthetic side.

There were two more prosthetic feet that were worn by two different subjects each, which provide similar results. Again the difference appears in the range. However, the phases of increase, decrease and return to the initial position within the GC are mostly congruent within the remaining data of this measuring location.

Conclusion

Although each subject wore a new foot in the second measurement the general shape of the bending curves for the heel region are almost similar between the own prosthetic foot and the new one. This result indicates a subject specific gait characteristic which remains dominant even if a remarkable intervention is provided by the new foot. Particularly the moments of the contralateral side seem to be not (or only slightly) affected by the different feet.

Despite this effect it seems that there is also a foot specific gait characteristic indicated by the similar shapes of the bending curves for the Quantum (Ortho Reha Neuhof). Further studies are required to analyze which of the both characteristics might have a stronger impact on the results. What can be stated is, that bending and torsional moments make the differences of prosthetic feet, and their influence on the contralateral side as well as on the gait pattern, visible. This opens a new perspective for the choice and modification of prosthetic feet next to the evaluation with kinematic e.g. camera systems and other kinetic measurement devices like force platforms. Bending and torsional moments therefore can be helpful for daily practice because they make stress at certain locations of the foot visible. More data and a further study could help to establish guidelines for the practical benefit of bending and torsional stress detection for e.g. surgeons, prosthetists and orthopedist.

Automated use of individual rhythmic movement initiation in neurological rehabilitation

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Introduction

As part of the demographic change, life expectancy is increasing and the population is growing older. This causes a higher need for medical care. The rise of neurological diseases (e.g. a 36 % increase in stroke rate from 2000 to 2025), in particular, and the decreasing stroke mortality rate requires a higher capacity in the area of rehabilitation. The increasing number of persons who have to cope with severe neuronal diseases or side effects (e.g. movement restrictions up to paralysis) need extended therapeutic resources and more effective therapy methods. To generate this capacity, it is essential to develop automated assistive devices for therapy, which are accepted by therapists and patients likewise. One approach is the automation of existing and effective manual therapy methods for patients with neurological diseases. In this process, the aim is to develop user-friendly and portable assistive devices.

Methods

A suitable therapy method which can be used for patients with neurological diseases is hippotherapy. While the patient is riding a specially trained horse, typical movement patterns, which are similar to the human walking pattern, are transferred to the human body. The moving sequences, which are created by hippotherapy, are transmitted to the brain by the spinal cord. Thereby, neuronal networks are preserved in the brain, synapses are newly interconnected and the information transfer of nerve tracts is improved. Thus the regeneration of injured regions is activated and restitution is supported. It is to note that in the early phase of rehabilitation, especially after an acute stroke, it is possible for patients to quickly and considerably improve their physical conditions. This can be reached by systematic and continuous exercising and the use of the brain´s neuronal plasticity. Even though studies have proven the effectiveness of hippotherapy, the method is expensive, laborious and not applicable for patients who are affected severely by neuronal injuries, afraid of horses/heights or who are allergic. A small number of therapeutic devices can be found on the market adapting the hippo therapies' movement pattern. However, the access to these devices is limited to patients which are able to sit.

Results

We have started the project IRBAN – individual rhythmic movement initiation - which is funded by BMBF, to open this therapy method to bedridden patients. Through this project, our aim is to develop an automated therapeutic device with an included therapy strategy. This strategy is based on a movement pattern created in the rehabilitation center of Ambulanticum in Herdecke. The therapy strategy refers to findings, which were obtained by the development of a treatment method, which is hippotherapy. Considerable therapeutic results, e.g. floating, harmonic moving patterns with a higher velocity, tonus regulation and improved balance have been achieved through the application of hippotherapy. In practice, the patient's pelvis is lying on the therapeutic device. The adapted movement pattern follows the course of a "lying three-dimensional 8". Thereby, the patient imagines moving his pelvis analog to the steps of a clock dial: "Middle – 4 – 2 – Middle – 8 – 10 – Middle". The automated movement path rotates by a maximum of 12° around the respective axes. Some of the advantages of the automated therapy device are the fact that training exercises can be individually adjusted and the possibility to document the patients' individual therapy in a transparent and objective way is given.

Conclusion

Due to the innovative automated exercise procedure, the therapist can reduce pressure from the physical hard work. Furthermore, it is possible to grow the group of patients who can use the therapeutically proved movement patterns of hippotherapy. Thereby, even patients with severe neurological diseases have the option of participating in an individual and well-directed therapy method. Moreover, the therapist can work with his patients more precisely and intensively. This makes it possible to focus on intricacies of the therapy exercises. Affected by this profound therapy improvement, patients are able to exercise longer and more intensively.