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# DEVICE FOR MUSCLE COORDINATION IMPROVEMENT

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**Abstract:** *Currently devices for improving muscle coordination are mainly installed in hospitals and used for rehabilitation after an injury. These devices are relatively expensive and are not publicly available for a wide range of users. A simpler and cheaper device would enable more common use of neuromuscular training. Especially senior adults would benefit from this kind of exercise. The device presented in this study is designed for training of the biceps and shoulder muscles. The coordination improvement is obtained by applying controlled resistance which can be adjusted according to the needs of an individual user.*
*Key words: Muscle coordination, neuromuscular control loop, free motion.*

## 1. INTRODUCTION

The lack of regular exercise or physical inactivity has been proved to have a relevant effect on the progression of many chronic diseases but even more important in the case of elderly people [1]. Exercise is also beneficial for improving quality of life, balance, and reducing the risk of falls [2]. One of the most common recommended exercises to improve arm muscle strength and coordination is small weight lifting. The problem with this kind of training is that the safety of the user is not guaranteed. Once the exerciser cannot handle the weight, it may end falling or hurting the muscles and the joint of the user. Also, in this kind of exercise the load cannot be altered. For different weights various dumbbells will be needed.


Fig. 1. Biodex System 4 Pro [3] isokinetic dynamometer is used for training joints.

Other similar devices such as isokinetic dynamometers (Fig. 1), provide constant velocity in the exercised extremity with variable resistance throughout a joint's range of motion. In the case of the elbow joint ranges from 0° to 120° [4]. This resistance is provided using an electric or hydraulic servo-controlled mechanism at a user-defined constant velocity [5].
The term 'isokinetic' is defined as the dynamic muscular contraction when the velocity is controlled and kept constant. Because of the biomechanical properties of the musculoskeletal system, the muscular force varies at different joint angles, offering optimal loading of the muscles in dynamic conditions [6]. Furthermore, unlike gravity loaded systems, this kind of exercise does not store potential energy providing safe training to the user [6]. The problem with this kind of equipment is that they are mainly designed for hospitals and mostly used for rehabilitation after an injury. For this reason, usually they are big,

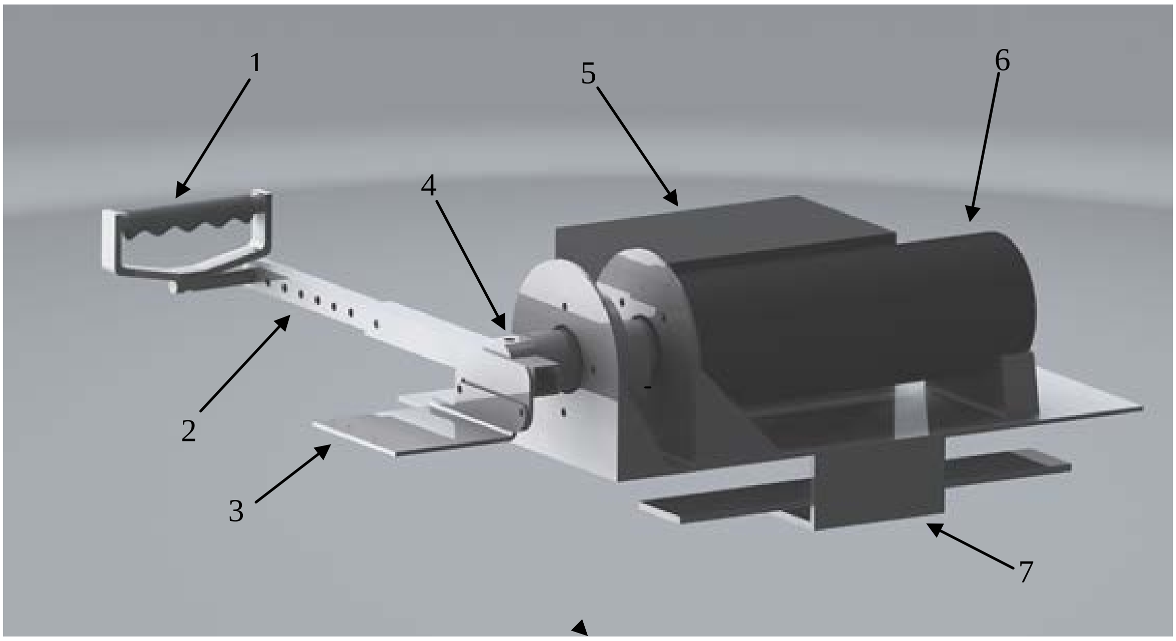

Fig. 2. Mechanical architecture of the device: 1. handle, 2. arm, 3. arm support, 4. arm and motor connector, 5. power supply, 6. DC motor, 7. clamps

expensive and not easily movable, limiting their accessibility for daily exercise. The implementation of simpler and cheaper devices would allow daily neuromuscular training for senior adults.

The presented device in this research uses either variable or static resistance to train neuromuscular system on the biceps and shoulder muscles. Using the device regularly will improve coordination while performing daily actions of elderly people, enhancing their quality of life. Overall, the reduced size of the machine and its adaptability to different users enables a wider range of users, not only for hospital or rehabilitation purposes.

## 2. METHODS

Device uses a geared DC motor for generating the load, which is applied to the user by a mechanical handle (Fig. 2). Motor is driven with an H-bridge circuit controlled with a Pulse Width Modulated (PWM) signal by the microcontroller. Feedback from the motion is measured with optical pulse encoder from the shaft of the motor.

The control logic for the load consists of different operating modes (Table 1). All of them prevent any rapid movements or loss of stability of the arm. The handle can be safely released anytime without leading to any dangerous movements. In the so called zero position, where the user doesn't apply any torque to arm, it stays in place. No torque is applied by the motor. When the user starts to turn the handle the torque steadily increases, until the maximum torque, depending on the settings and operating mode, is achieved. Handle will continue rotating with constant torque over this point. If the user can't hold the handle or lets it turn back, the torque is steadily reduced until the handle has rotated back for a predetermined angle. This doesn't mean the handle rotates back to the same zero position where the movement began, but the zero position follows the rotation. This way, the handle always rotates back just a little and the load stays safe. Even when the handle is completely released, it only rotates back about the same amount. This kind of operation ensures the safety of the exercise, unlike the small weight lifting where the weight drops if released.

In the simplest 'static' operating mode, the torque on the handle stays on a constant value which can be adjusted with one of the potentiometers. In the 'dynamic' operating mode the load consists of static part and the dynamic part which are summed together. The dynamic part of the load is basically a sinusoidal signal of which frequency and percentage of the total load can be adjusted with potentiometers. The third operating mode, 'external' uses an analog input where load can be applied as an analog voltage between 0 to 5 Volts. This option makes it possible to vary load for example with music. The waveform is extracted from the analog signal and it is used to generate the load for the handle. The amplitude of the load as well as the percentage of the dynamic part of the load can be adjusted with potentiometers just like in the case of the 'dynamic' operating mode.

| Mode | Description | Variables |
|---|---|---|
| **Static** | Adjustable but constant load. | The value of the load |
| **Dynamic** | The load is variable according to a sinusoidal wave. | The amplitude and frequency of the wave. |
| **External input** | The variation of the load is taken from an external analog signal. | The amplitude and the frequency of the signal. |

Table 1. Summary of the different modes and the adjustable variables.

The built prototype has a simple interface for adjusting the load according to the needs of the user. This interface consists of three potentiometers, a switch and a liquid crystal display (LCD). The switch is used for selecting the operating mode. The active mode and all the user adjustable parameters are shown in the LCD. One potentiometer sets the upper limit of total load and in 'static' mode this is the only parameter that is needed to adjust. Second potentiometer adjusts the percentage of the dynamic part of the total load. Finally, the third one adjusts the frequency of the sinusoidal signal in the 'dynamic' operating mode.

The use of dynamic load instead of static one, when training body has been studied several times, but literature shows [7] that there is not a clear neuromuscular improvement on dynamic load compared with static training. Yet, some of the researches showed that the use of low frequency (30-50Hz) vibration may have an acute outcome in vibration training [7]. This is the reason why it was decided to keep both options available, including a third different option which would help train also the memory of the user.

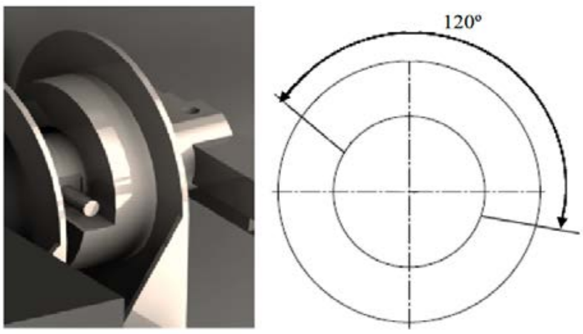


Fig. 3. Mechanical limit switch to ensure user's safety.

The control logic ensures that the applied load always stays stable and safe, but in case of failure, there are both electrical and mechanical limits for protecting the user (Fig. 3). Electrical limits force the H-bridge control signals to OFF state in case of the failure of the microcontroller. This prevents the handle to turn to unsafe angles. In addition, there are also mechanical limits that make it impossible to turn handle to angles where the user could get hurt.

The actual device is designed to be compact and easy to move. The actual mechanical structure has two separate functions. First, it has to be able to transfer torque of the DC motor to the arm of the trainer. The second task is to support and

make sure that the device does not move while exercising with the device fastened to the table.
Transferring the motion to the trainers arm is made by using extension of the shaft, extra bearing, support of the arm and the handle. The most visible of those parts is the handle. The length of the arm can be adjusted to fit the trainer's dimension. The support of the arm is made so that the angle can be modified, which ensures that the arm rests along the whole support, distributing the resistance force uniformly.
The mounting of the motor can be performed by clamps or bolts. The clamps are designed to able safe mounting to different kind of tables. The robust and heavy structure of the device ensures safe training.
One challenge of the mechanical design is to ensure that the range of the motion is wide enough. The DC motor is lifted over the base plate to make sure that the training angle is not too limited. So, the movement of the arm is limited in the other end by the table, but in the other end movement is limited by the trainer. Trainer can control the length of the rotation movement by adjusting the position compared to device. Therefore the seat height is one key parameter that is affecting to the training experience. The height of the table has to be taken into account when choosing the place for the device.

## 3. RESULTS

The equivalent mass resistance generated by the motor were measured with a force sensor placed between the handle and the flat surface, so that the sensor measured the force generated by the motor. Actual force needed to rotate the motor varies depending of the distance between the axle and the handle.

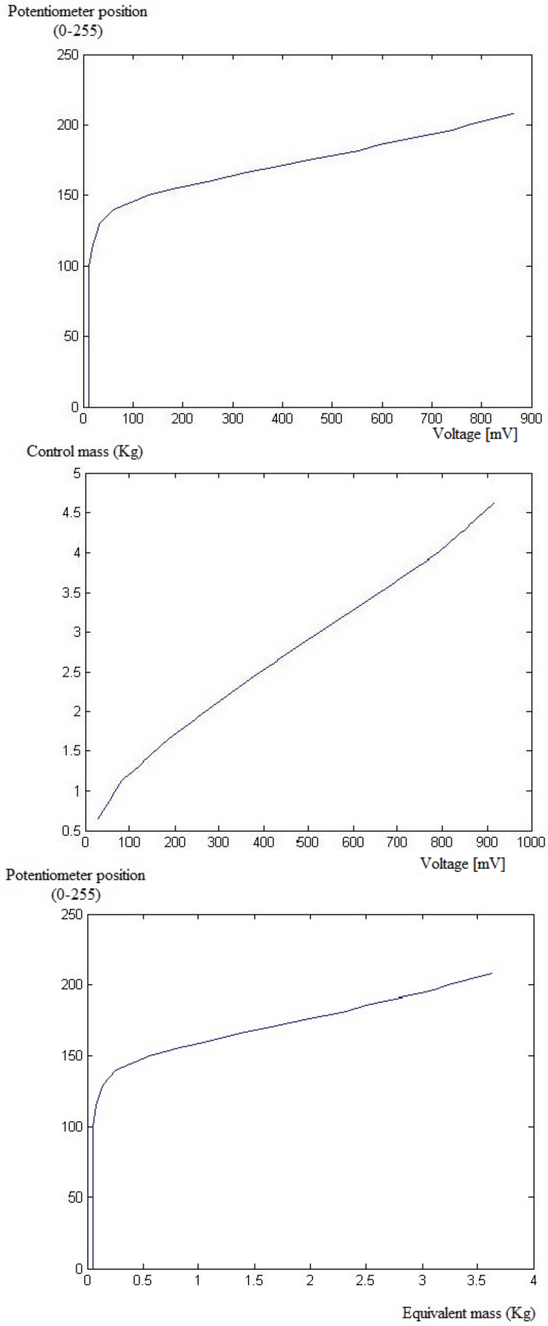


Fig. 4. Measurements for the static mode. First, the measured values by the sensor in mV, next the read values with the control masses and finally the conversion of the read values to kilograms.

The measurements were made using estimated average distance. To be able to convert the measured values into equivalent mass values, different control masses were used and measured with the force sensor as

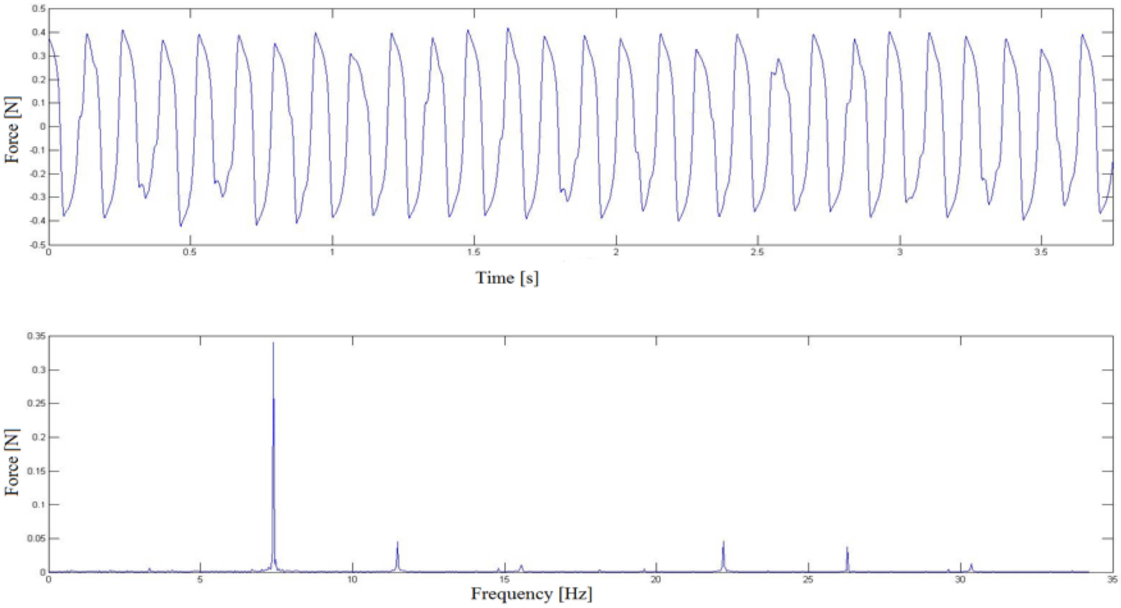

Fig. 5. Measured values in the dynamic mode with a 7 Hz frequency signal

shown in Figure 4. Also in Figure 4 the load values for the different positions of the potentiometer after the conversion are shown. Those values represent equivalence of the load to the free dumbbell (when arm is in the horizontal position). The minimum load is aprroximately 0.4 kg and the maximum about 4 kg. The maximum torque of the motor is limited by power supply. The maximum torque can be increased by changing more powerful power supply, which enables using modified construction to larger muscle groups. The minimum load is determined by the resistant torque of the gearbox, bearings etc.

In Figure 5, the upper graphic shows the measured force by the force sensor. The frequency of the dynamic signal is 7 Hz, which can be seen as a main signal on the graphic below along with other different frequency signals produced by some disturbances in the measured values.

## 4. DISCUSSION AND CONCLUSION

The described prototype demonstrates to be a beneficial alternative to the actual arm muscle exercise machines. The device provides both enough resistance (max. 4 kg) to work the muscles and the possibility to modify the variable load according to the user to improve the neuromuscular system.

In the measurements the accuracy of the sensor may have altered the real resistance provided by the motor. The quality of the gearbox and the alignment of the shaft may have affected the accuracy, as well.

The prototype could be redesigned to reduce the size and the actual 12 kg mass of the machine. Not only the motor and the power supply are oversized, the mechanical structure is designed to be made out of steel. Other materials such as aluminium could be used and the sizing of the elements could be optimized. Nevertheless, it is proved that smaller and cheaper devices could be developed for daily muscle exercise by elderly rather than isokinetic dynamometers or dumbbells.

Further development could be done to implement other technology to improve the experience of the user. Technologies such as connecting the movement of the arm to a visual interface, for example a game where the user should have to keep a point in the middle of a circle by trying to move the arm with a constant velocity. Other option will be to link the movement with music, that way the load will follow the music so the user will be able to predict when should apply more or less force to continue the movement steadily. These implementations will be beneficial to train not only the body but also the memory of the user.
Similar devices could be designed to exercise other parts of the body (e.g. legs or hip), helping elder people with some issues such as stability while standing or reducing the risk of falls.

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