BCI controlled FES-hybrid orthosis
to enable reaching and grasping in
high lesioned tetraplegic subjects

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Introduction
The application workpackage “motor substitution” of the TOBI project is aiming at the restoration of the hand grasp and elbow movements in spinal cord injured individuals and in stroke survivors. Today the only possibility of significantly improving a restricted or lost grasp function is the application of Functional Electrical Stimulation (FES). However, current FES methods are only applicable if shoulder and elbow functions are preserved to a large extent to enable a movement of the whole arm [1]. If these functions are missing, the corresponding muscles of the upper arm can be stimulated only for a short period. This can be ascribed to rapid fatigue due to the non-physiologic synchronous activation of the nerve fibers through external electrical pulses. Moreover, in high lesioned tetraplegic subjects only a few motor functions are preserved that can be used for control of assistive devices. Therefore, the aim of this work was to develop a FES-hybrid orthosis to overcome these limitations. In addition, a sophisticated control concept for integration into the hybrid-BCI concept is introduced.

Components of the FES-hybrid orthosis
The main components of the orthosis consist of an in flexion direction self-locking, electrically delockable elbow joint [2] and self-adhesive gel FES electrodes in combination with a multi-channel electrical stimulation device (“Motionstim”). Its dedicated firmware allows for autonomous use and shared control. To fully support the functionality of the hardware of the orthosis, several software tools for its central processing unit “Motionstim” have been developed. These include an application program to control the actuators of the orthosis and the implementation of a standardized serial communication protocol.

Control scheme of the FES-hybrid orthosis
The switching between the control of the elbow and the hand and the access to a pause-state is done by a digital command signal provided by a SMR-BCI (figure 2). Within the active control state the degree of elbow flexion or the degree of hand opening / closing is controlled proportionally via an analog signal originating from a shoulder joystick.

After initial calibration of the shoulder joystick, the system enters the pause-state without stimulation and an unlocked joint. In order to control the elbow, the user emits a "toggle pause"-command to enter the "Arm-active-mode". Now, the user has to move the shoulder joystick into a neutral position, the stimulation of the elbow flexor muscles is turned on and the joint is delocked by activation of a solenoid driver. If the flexion moment is insufficient, the user may increase the stimulation pulsewidths and therefore the generated flexion force by simply moving his shoulder more forward. A user initiated selection of the control state of the hand automatically locks the elbow joint. The analog signal from the shoulder joystick is then used for control of the degree of hand opening or closing. If a user switches back to elbow control the pulsewidth values of the stimulation channels for the grasp generation are hold at the current command level. If a user returns to control of the hand grasp, she/he is first asked to move the shoulder joystick to the position where he formerly has "frozen" the command signal. This prevents an unwanted release of grasped objects. To ensure a correct alignment to the former positions of the joystick users are guided by an acoustic signal.

References:

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