TRAINING INDIVIDUALS TO USE PATTERN RECOGNITION TO CONTROL AN UPPER LIMB PROSTHESIS
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INTRODUCTION

Pattern recognition has been used in the laboratory for control of advanced prosthetic limbs. However, recent work has shown that it has the potential to improve control of existing clinical prostheses [1]. Targeted muscle reinnervation (TMR) makes it possible to access neural information from residual peripheral nerves that previously innervated the missing limb [2]. Pattern recognition allows this information to be extracted and used by individuals with high-level amputations for effective prosthesis control. TMR is not necessary for pattern recognition control at the transradial amputation level [3]. Here, we outline a sequence for training individuals to use pattern recognition control of elbow movement, wrist rotation, wrist flexion/extension, and hand grasps. We highlight the differences between training for direct control and training for pattern recognition control. We also recommend a training protocol to facilitate mastery of pattern recognition control before and after being fitted with a prosthesis.

TRAINING PROGRESSION

Teaching the concept of pattern recognition control

Understanding pattern recognition control is the first challenge for individuals with an amputation. We begin with verbal explanations of pattern recognition, including the fact that each electrode location no longer corresponds to a specific movement (as in direct control), and that consistent patterns of muscle activation are required for each movement. We encourage the individual to actively participate in training. The process of selecting shared vocabulary such as “channel,” “signal,” “degree of freedom,” “supination,” or “key pinch,” engages the individual as a partner in the process and invites their active participation. Agreed-upon terminology also ensures clear communication between the individual and the clinician.

Once electrode sites are located (typically 6 for the transradial level and up to 12 for the shoulder disarticulation level), we use a myoelectric signal viewer that shows patterns of myoelectric activity corresponding to movement attempts. This illustrates to the individual how they are able to produce identifiable patterns of muscle activity for a given movement. We are also able to use virtual reality software to provide feedback to the individual as they attempt control.

We explain the importance of performing the intended movements with a moderate level of effort to avoid fatigue, and the necessity of duplicating the level of effort for each movement, as a significant change in effort may confuse the classifier. Frequent retraining of the classifier is performed in initial training sessions because of physiological changes, such as altered skin conduction, or alterations in movement attempts that occur as the individual adapts to the training process. It is explained to the individual that retraining is expected and will be part of the routine, although it may become less frequent as they gain experience in using pattern recognition control.

Phantom limb considerations

It is appropriate early in the training process to discuss the role of the phantom limb in pattern recognition. It is necessary to determine if the phantom limb will be useful during training. Users should be instructed to try to move their phantom limb in the desired direction, even if it feels immobile. Some individuals experience pain or cramping when attempting to move the phantom limb; this discomfort may interfere with successful control. In this case, we instruct the individual to use a moderate level of effort, to focus mirroring the desired movement with the intact limb, and to allow time for relaxation of the phantom limb. Photographs of exercises to be performed with the phantom limb are useful and can be included in a home exercise program in preparation for the next training session (Figure 1).

Pattern recognition training for individuals with transradial amputation

Initial training sessions utilize a virtual arm with which the individual first experiences pattern recognition control. We begin pattern recognition classifier training with the degrees of freedom easiest for the individual to control—hand open and close for the transradial level. Individuals with transradial amputation must learn new motor commands: in pattern recognition control, the individual is being asked to perform a movement that he or she is not accustomed to controlling intuitively. With direct control, wrist flexion and extension are used to open and close the...
hand, whereas physiologically appropriate muscles are used in pattern recognition control. Frequent rest breaks may be needed as fatigue is common when learning new muscle activation patterns or when a myoelectric prosthesis has not previously been used.

Next we try adding degrees of freedom outside of the individual’s experience. For individuals with transradial amputations, these are wrist flexion/extension and multiple grasps. This provides an opportunity to demonstrate to the individual the potential for pattern recognition to enhance prosthesis functionality and to highlight the amount of motor-control information available in the residual limb. The concept of ‘retraining’ should be discussed again with the individual, as retraining the classifier is indicated whenever control seems degraded or a new degree of freedom is added. Activities that demand an extreme arm position, such as overhead reach, may also require retraining.

Pattern recognition training for individuals with transhumeral or shoulder disarticulation amputations and TMR

Individuals with higher-level amputations and TMR begin classifier training in the virtual reality environment with elbow flexion and extension. We progress quickly to an added degree of freedom, usually hand open and close, which is available with direct control in conventional myoelectric prostheses. Because there is more control information available in the residual limb after TMR, pattern recognition affords intuitive control of two degrees of freedom at the wrist and multiple grasps. Activating three or more degrees of freedom demonstrates to the individual the potential of pattern recognition control. At the end of the first session, it is appropriate to send the individual home with a program to exercise new motion attempts with their residual and phantom limbs.

Subsequent visits for pattern recognition training will begin with a review of the exercise program, or any symptoms related to unaccustomed use of muscles. It is beneficial to repeat the discussion of pattern recognition concepts while setting up for the training session and to begin working with the degrees of freedom that were successful at the last visit. It may be appropriate to train and test two or three degrees of freedom using virtual reality programs.

If there are any unintended movements, some time might be devoted to distinguishing actions based on verbal information from the individual. The subject may need to describe or demonstrate the movement with the intact limb. Make clear that the pattern recognition control model does not allow for ‘parallel’ classification: only one decision (or movement) can be performed at a time. Also, during training, ‘no movement’ classes are important for distinguishing between movement classes. As degrees of freedom are mastered we add more degrees of freedom, up to the capability of the prosthesis intended for use.

Evaluation of control in the virtual reality environment

When control in the virtual environment has been mastered, control can be assessed using the Motion Test and the Target Achievement Control (TAC) Test [4]. In the Motion Test, the individual is randomly prompted to perform a single movement. The movement has to be completed within a given time frame, and inadvertent movements are ignored unless they directly oppose the requested movement (such as wrist flexion performed during a wrist extension trial). In the TAC Test, the trainee must sequentially position one or more degrees of freedom to achieve a target posture, and misclassifications must be corrected within an established time frame for the trial to be considered successful. This increases the difficulty and lets the clinician focus on the most challenging aspects of control. The time frame and tolerances for the TAC Test can be adjusted as performance improves.

Pattern recognition control of a prosthesis

As the virtual arm avatar does not change with respect to position in space, it is necessary to move away from training with virtual reality to training with a prosthesis. Controlling a prosthesis remotely (Figure 2) is a tool used during the early sessions before a socket is fabricated.
The socket is usually completed by the third or fourth session, and pattern recognition training while wearing a prosthesis can begin. Training is done with the arm supported or unsupported in approximately 45 degrees shoulder flexion. It may be necessary to collect training data both while the individual is standing and when he or she is sitting. Proximal postural effects, weight of the device, prosthesis position relative to gravity, and length of residual limb all affect direct myoelectric control and will likewise affect pattern recognition control. To train for functional prosthesis control and use, we introduce common objects for grasping and change their orientations to provide a variety of pre-positioning demands. Reminders to perform the movements in the same way as during training are helpful. The addition of the prosthesis and the introduction of increased functional demands add to the challenge. Again, it may be necessary to remind the individual that the classifier may need to be retrained.

The individual probably does not have experience using a prosthesis with powered wrist flexion and extension or multiple grasps. It is useful to guide the individual during prepositioning while they are accessing the new functions of the prosthesis instead of using customary postural accommodations (see Figure 3). Prepositioning demands increase as additional degrees of freedom are included in the classifier, until all degrees of freedom possible with the prosthesis are utilized.

The clinician should suggest alternative prepositioning techniques that use wrist flexion/extension or alternate grasp patterns to demonstrate the added potential of the prosthesis. Simple functional tasks like the ‘clothespin relocation task’ and The Southampton Hand Assessment Procedure [5], can be useful for developing prepositioning skills and measuring progress.

Allowing individuals to watch video of themselves using the prosthesis is instructive in demonstrating progress. Watching video of others who have mastered pattern recognition control of a similar device can also demonstrate the potential of pattern recognition control. The next stage in training for pattern recognition control is to integrate function of both extremities. Bimanual function is essential and increases the complexity by another degree. Initially the intact limb is somewhat passive, performing a holding function. Gradually, simultaneous action using both limbs is encouraged in activities such as folding towels, using a tape measure, opening cupboards, and picking up and carrying a tray or basket. Actions can then progress to alternating limb activities such as hanging clothes, opening packets, using scissors, and cutting fruit. The individual is encouraged to decrease the amount of visual attention paid to the prosthetic terminal device.

Once the individual has reported satisfaction with the performance of the prosthesis and can demonstrate basic skills, cognitive demands in functional tasks may be increased. Tasks are given in which more organization and planning is required for successful task completion and divided visual attention is needed to perform the task in a timely manner: prepare a meal, pack a suitcase, assemble bookshelves, or sew on a button. Verbal cues to retrain may be needed if unusual positions affect control. It is also useful to take this opportunity to do an Assessment of Capacity for Myoelectric Control [6] to get a baseline score of control.

**FUTURE WORK**

Our experience with pattern recognition control in the home and community to date is limited. Due to upcoming software and electronic improvements, further training development will be needed. We anticipate advancing the application of pattern recognition control to the home environment in the near future. We look forward to further refining our approach to training individuals with amputations at all levels in the use of pattern recognition control with conventional and advanced prosthetic devices.
REFERENCES


