ROLE AND IMPORTANCE OF BIOFEEDBACK AND PROPRIOCEPTION IN IMPROVING THE FUNCTIONALITY AND ACCEPTANCE RATE OF UPPER EXTREMITY PROSTHESIS: A REVIEW

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ABSTRACT

Study design: *Literature Review*

Background: *Loss of upper limb dramatically decreases the quality of life & is a challenging task for prosthetic rehabilitation. Many functional limitations in the prostheses decrease the acceptance rate by users. For upper limb prosthetic users, absence of sensory feedback & proprioception impedes efficient use of the prosthesis & is highlighted as major contribution for improvement of functionality and acceptance rate of prosthesis.*

Objective: *To review the role & importance of biofeedback & proprioception in improving functionality & acceptance rate of upper extremity prosthesis.*

Method: *An electronic database search was conducted using Google scholar and Pubmed databases and reference lists from all retrieved articles.*

Result: *After reviewing literature, it was found that upper extremity prosthesis those incorporate these factors biofeedback and proprioception finally lead to improved functionality and acceptance rate.*

Conclusion: *Upper limb prosthetic functionality is ultimately dependent on user's ability to efficiently manipulate and interface with their prosthesis. It follows that having intuitive control would increase the utility of device.*

Clinical relevance: *Review was done to conclude potential value of artificial proprioception and sensory feedback for end users. Various sensory feedback systems and proprioception techniques have been proposed from literature for clinicians' awareness and application of same in clinical practice to bridge gap to improve functionality and acceptance of upper extremity prosthesis.*

(Word count: 217)

Keyword: *Upper extremity, Prosthesis, Amputation, Functionality, Acceptance rate, Biofeedback, Proprioception.*

1. BACKGROUND

Upper limb loss is one of the most difficult challenges for prosthetic replacement due to the complexity of fine sensory input and the dexterous function of the hand. Loss of a hand and arm may reduce life quality dramatically, leaving a person feeling less capable and more dependent. This has been found that the loss of an upper limb is much more life-altering than the loss of a lower limb, and effective diagnosis of an upper limb amputee and effective prosthetic prescription have the potential to significantly increase the quality of life of an amputee. Unfortunately, the rate of rejection of upper extremity prostheses is common and can be approached by 38% for more proximal amputations. Amputations at the forearm level are correlated with the highest acceptance rate, meaning that the acceptance rate for upper limb prostheses can be improved by concentrating on these two parameters.[1],[2]

1.1 Biofeedback Control

The term biofeedback is used to characterize the use of instrumentation by providing timely and reliable visual and/or auditory representations of the process in order to make the secret physiological process transparent to the user. Biofeedback is a mind-technique requiring the use of visual or auditory signals to obtain control over subconscious body functions which may include conscious regulation of factors such as heart rate, muscle tension, blood flow, pain perception, and blood pressure. This method involves adding sensors to a system that provides input on various aspects of the body.[3],[4]

Sensory feedback systems use prosthetic instrumentation (or sensors) to sense an external stimulus. This instrumentation in effect drives the output of a haptic feedback system that transmits information about the external stimulus to the prosthetic user. The literature described different types of tactors, depending on methods such as vibration, pulling or shear force to transmit the external stimuli to the user. The method used for communicating information to the user via the tactor is known as the feedback signal. The sensory feedback systems analyzed were divided into three categories: Somatotopically matched, modality matched and substitution.[1]

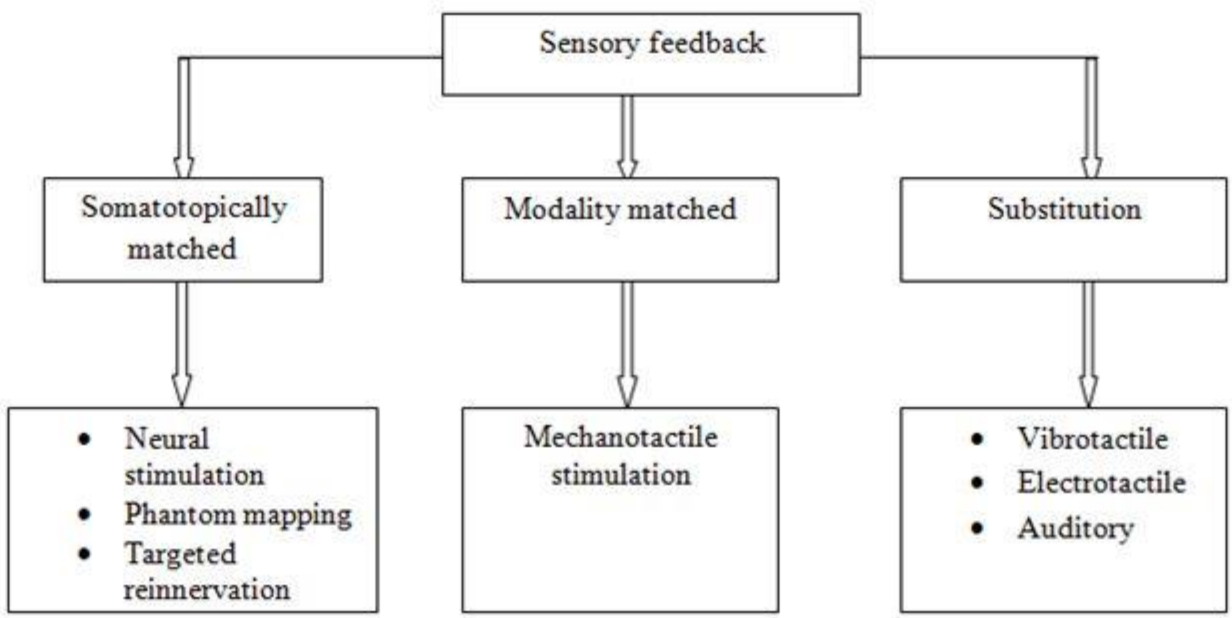

Figure 1: Categories of sensory feedback[1]

Somatotopically matched feedback

Somatotopically matched strategies offer feedback such that an amputee feels the stimulus as if it were applied to the same location of the missing limb.[1]

Table 1: Description of various somatotopically matched strategies[5],[6],[7],[8],[9],[10],[11],[12],[13]

Methods	Description
Neural stimulation	Natural physiological feedback can be restored using invasive neural electrodes by strategic electric stimulation of nerve afferents. Tactile sensations such as touch, pressure and proprioception, as well as sensations of location and movement inside the missing limb have been reported to amputee participants.
Phantom mapping	Phantom mapping is based on the ability to actively emit these phantom sensations as a result of residual limb stimulation. This feedback technique involves the identification of areas on the residual limb of an amputee that frequently trigger sensations that relate to the missing hand.
Targeted reinnervation	TR is a surgical technique that transfers motor and sensory nerves that previously innervated the amputated limb to target sites of the muscle and skin. This operation was initially carried out to increase the number of motor control sites for myoelectric prostheses and allow intuitive control.

Modality matched feedback

The knowledge conveyed to the user is sensationally matched, for example touching the prosthesis is perceived as touching the skin, although not matched locally. These systems theoretically require lower cognitive demand because the user does not need interpretation of the feedback signal modality. Typically, modality-matched feedback methods communicate tactile information to the amputee using pressure or force applied perpendicular to the skin.[1]

Table 2: Description of method of modality matched feedback [14],[15],[16]

Methods	**Description**
Mechanotactile feedback	Mechanotactile feedback is commonly used to communicate the touch and grasp conditions of the prosthetic prehensor to the user. These systems translate the touch or grasp of force information from the prehensor as a perpendicular force or pressure applied to the strategic location of the residual limb or body of the amputee.

Substitution feedback

Sensory feedback strategies provide the individual with a sensory input that is not physiologically indicative of what the missing hand or arm would experience. The effectiveness of the method depends on the ability of the user to understand and relate the type and location of the stimulus to the prosthesis. The most common approach was to use vibration, electronic or auditory stimuli to transmit tactile information from the prosthesis to the amputee.[1]

Table 3: Description of various methods of substitution feedback [16],[17],[18],[19], [20] ,[21]

Methods	Description
Vibrotactile feedback	Vibrotactile response involves the transfer of sensory information from a prosthesis to the user through mechanical vibration application in a strategic region of the skin of the user.
Electrotactile feedback	Electrotactile feedback provides the user with sensory information through electrodes placed on the skin of the user.

Auditory feedback	Auditory feedback Methods provide information on the condition of a robot or prosthesis by various tone or sound frequencies.

1.2 Proprioception

Proprioception is "the awareness of joint movement, body movement and body location in space." At the present time, both "proprioception" and "kinaesthesia" exist in the published literature. Some researchers define proprioception as a common sense of joint position, and kinaesthesia as a conscious understanding of joint motion, whereas others consider kinaesthesia as one of the submodalities of proprioception, and proprioception as a structure contains a common sense of position and a sense of joint movement. Accordingly, it was argued that it is reasonable to view "proprioception" and "kinaesthesia" as synonymous.[22–26]

Proprioception plays a key role in helping people to move consciously and to communicate with their physical environment. New technology in upper-limb prostheses does not provide amputees with proprioceptive knowledge about the condition of the limb as it starts to integrate some haptic feedback. Therefore the wearer must control the limb visually, which is sometimes difficult or even impractical for certain tasks.[27]

Extended Physiological Proprioception (EPP) regulation involves linking the movement of the prosthesis joint to the movement of an intact joint in such a way that the normal proprioceptive input of the patient in the intact joint is directly related to the state of the prosthetic joint.[28]

In the direction of externally powered prosthesis, EPP could be realized by coupling the prosthesis function to residual joint motion in a position-servo relationship where the input cannot beat the output. For such a system, prosthesis joint location and movement are at all times directly related to the location and movement of an anatomical joint being physically bound to maintain a continuous interaction between it and the prosthesis. The method is a position servomechanism in which the input is physically bound by the output, so that the input cannot be carried forward or dropped behind the output, even temporarily. This relationship takes on added significance relative to a fundamental hypothesis in the theory of motor control, which states that coordinated movements are not described as joint muscle schemas at the higher levels of the central nervous systems, but rather function as topologically oriented engravings that can be converted into specific joint muscle sets.[12]

EPP can be introduced using different schemes: harnesses and cables. Prosthesis regulation by harnessing body motions has the intrinsic potential to fully implement the concepts of extended physiological proprioception. No use is made of the feedback paths left when regulating prosthesis with myocontrol. Myocontrol needs to be used as an open loop system.[29],[27]

Cineplasty is another control choice which meets extended physiological proprioception. Cineplasty provides excellent feedback capabilities, but it remains incompatible with cosmetic demands put on prosthesis. EPP provides direct monitoring of the functioning of the natural limb by enabling the patient to see the prosthesis proprioceptive. It is accomplished by connecting the remaining tendons or muscles of the amputated limb to the prosthesis mechanically, using cables. This enables the patient to monitor the prosthesis without the optical feedback needed for other control topologies, such as myoelectric control.[30]

Proprioceptive motion feedback has also been found to improve the rate of performance and ease of use, although it has resulted in slower movements. The improvement in success rate and ease of use rating showed that in both sighted and non-sighted situations proprioceptive motion feedback was helpful.[27]

Therefore, both efferent motor control and afferent sensory feedback are strongly dependent on the execution of dextrous hand movement. Sensory feedback systems rely on exteroceptive and proprioceptive information to higher brain control centres and are responsible for detecting grip strength and hand position, as well as object shape, compliance and textures. Upper limb prosthetic functionality essentially depends on the ability of the patient to operate the prosthesis effectively and interface with prosthesis. It follows that intuitive control would make the system more useful.[1]

2. METHOD

A computerised search was conducted in Google scholar and Pubmed by using key words: Upper extremity, prosthesis, amputation, functionality, acceptance rate, biofeedback, and proprioception. In addition, references are screened for other relevant articles. Flow chart ahead represents the process followed for this paper.

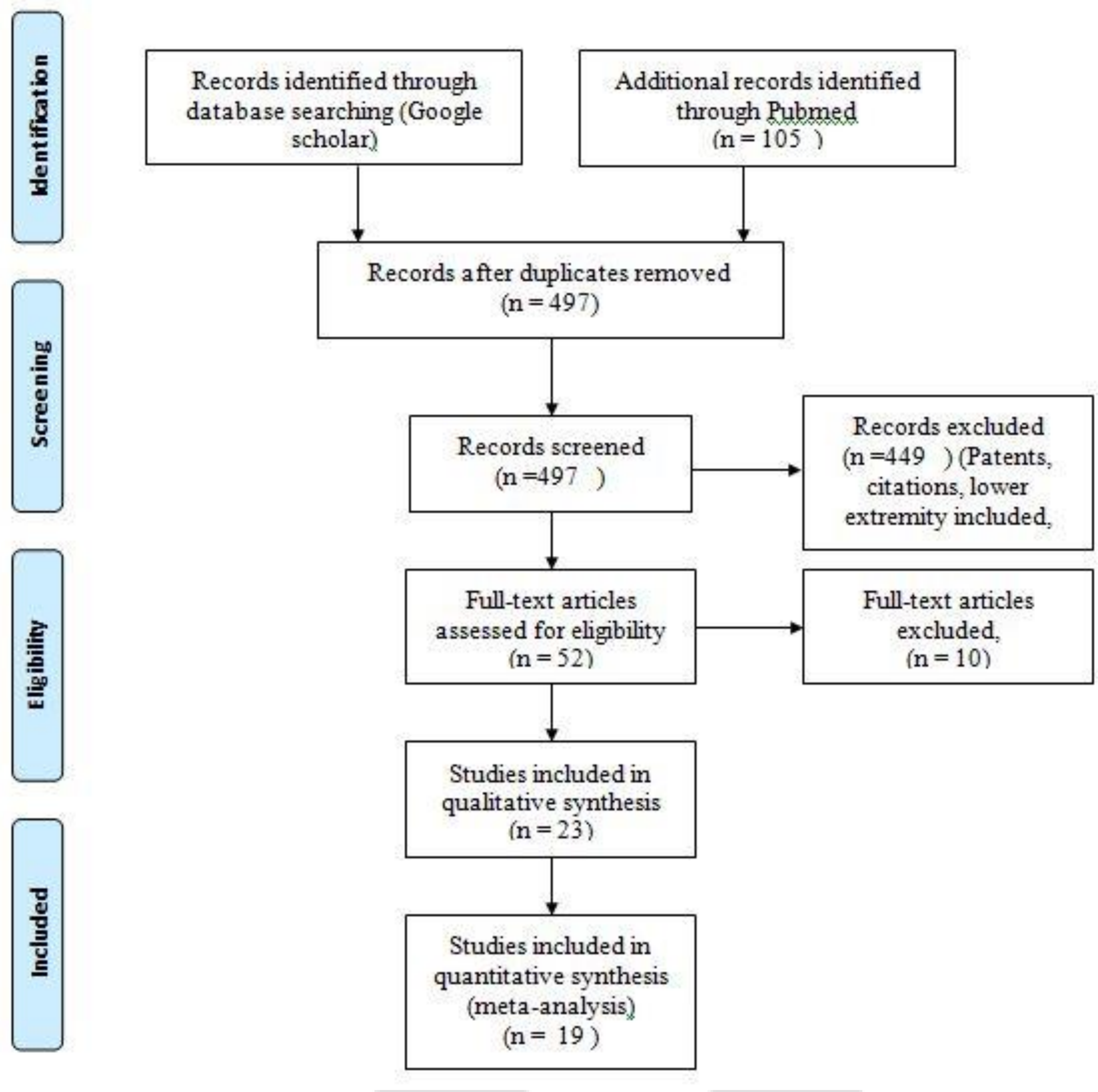

Figure 2: Flowchart

3. RESULT

As we know, proprioception and biofeedback are two essential factors that play a crucial role in enabling stump and prosthesis to move actively and interact with their physical environment, so we abstractly expect artificial proprioception and biofeedback to be sufficient for the natural use of upper-limb prostheses, which would also considerably increase the rate of acceptance of upper limb prosthesis. Following is the conclusion drawn after review of the literature available:

Implementation of proprioception and sensory feedback: Proprioceptional control is exhibited by a prosthesis system if and only if the user can control at least one mechanical output quantity of the prosthesis (e.g. force,

velocity, position or any function thereof) within a finite, useful, and essentially continuous interval by varying his/her control input within a corresponding continuous interval. This is supported by the reviewed literature as Myocontrol provides little proprioceptive input or knowledge to the user about joint position, speed of movement and grip strength. As the restriction comes from the traditionally used upper limb prosthesis these are deficient in proprioception. These are some examples that get introduced into the upper limb prosthetic development to enhance the proprioception in specific population such as Open windows of ergonomic and sauter socket designs used in transradial amputation allow for increased heat dissipation and increased proprioception. Additional benefits of both designs are increased donning facility and increased ROM. The combination of supracondylar socket and silicone sleeve will ensure superior suspension for better performance.[31],[32]
The lack of sensory input from prosthetic to patient has been highlighted for decades as a major barrier that hampers prosthetic usefulness in the upper limb. Today, due to the rapid advances in multifunctional prostheses this problem has become even more important. Various sensory feedback systems have been developed, and several have shown that a user can enhance their ability to control input on the prostheses. However, a sensory feedback system outside of a research setting has yet to be proved successful for long-term use.[33]

Impact and acceptance rate on functionality of upper extremity prosthesis: Prosthetic selection should be based on the individual needs of a patient and should include personal interests, prosthesis knowledge and functional needs. This research demonstrates a lack of empirical evidence with respect to functional variations in upper-limb prostheses.[34]

As literature review stated that the primary prosthesis rejection rates include lack of perceived functional changes, weight of prosthesis and socket discomfort and higher rejection rates correlate with higher amputation levels, congenital loss of limbs, students and females.[32]

Myocontrol provides little proprioceptive input or knowledge to the user about joint position, speed of movement and grip strength. Conversely, when someone has already adopted MYO prosthesis as their primary device, they appear to receive enhanced sensory feedback, including proprioception, in connection with prosthesis.[34]

The most advanced upper limbs prosthetic that all give much greater functionality than any previous single device with 1 or 2 sensors, both rely on myoelectric control too.[35]

A new method for closing the loop of myoelectric prostheses has been demonstrated: Instead of just supplying the system output as feedback, i.e. the traditional system input approach (EMG signal) has also been fed back to the user. The EMG Biofeedback increased the efficiency by a significant amount in the routine grasping and force tracking tasks.[36]

Controlling the prosthesis for an amputee below the elbow is therefore often intuitive and easy to know in a suitable rehabilitation setting.[37]

The extent of the loss of limbs is one of the most commonly studied and conclusive features of predisposition associated with the use of prosthesis. Prosthesis acceptance typically declines at both higher limb loss rates where devices are significantly heavier and require higher energy expenditure to operate. It is especially important for amputees to be able to get sensory feeling through prosthetic aids. Prosthesis usually delivers object handling features.[38] Control of the myoelectric prosthesis is for specific sports or work activities or as a more natural and less strenuous movements of the hand and elbow units are independent of the position of the body. For high level amputees, whose physical impairment is severe, the electrically powered prosthesis is a viable alternative to the cable operated prosthesis, because it provides a greater range of function and requires less energy expenditure.[33]

The ultimate prosthesis would provide sensory input in the form of proprioception, allowing an amputee to fine-tune the terminal device without relying solely on visual feedback. This must be comfortable, functional and have a pleasing appearance for any prosthesis to be recognized and used by the amputee. Amputees stated the electrically-powered prosthesis was the most favoured prosthesis. The cable powered hook was the second favourite followed by the hand operated by the cosmetic and cable operated hand. The high acceptance rate at the below-elbow level of 82%, 86% at the above-mentioned elbow level and 100% for high-level amputations for electrically powered prosthesis is very positive and it appears that amputees are strongly in favour of this prosthesis, particularly high-level amputees.[39],[33]

4. DISCUSSION AND CONCLUSION

Upper limb amputation is one of the complex trauma that rehabilitates the amputee, since the motor control of the hand provides a fine grip and grasp that is impossible to replicate in the prosthesis. Earlier, different passive hands are used only to provide the cosmetic appearance then developed by using sensory and proprioception input of these two techniques.[1]

One study reported that most amputees (68%) who have abandoned or rejected prosthetic use may be willing to reconsider using prosthesis if improvements in technology were made at a reasonable cost. Advances made through the Revolutionizing Prosthetics program have the potential to benefit prosthetic and non-prosthetic users.[40]

One research found that while Vibrotactile feedback improved grasping performance using complex control techniques, it did not improve control when visual feedback was already being used. Throughout amputee research, the vibration amplitude and frequency were used to communicate the grasping forces present in a prosthesis prehensor. One research reported participants describing the sensation as similar to tiny bursting skin bubbles. Many studies do not mention the specific sensations felt by the participants as a result of the electrocutaneous feedback; they describe the range between initial sensation and pain, instead.[41]

Gonzalez et al. performed capable experiments for an auditory scheme using the sounds of a cello to indicate thumb movement and an index finger movement violin. These two instruments will play a particular starting note and a final note during the grasping process to indicate the task is completed successfully. A separate, distinct note for each finger signified errors in the finger trajectory in order to remind the user of the need to correct the movement.[42]

A research by Amy Blank et al examined the role of proprioceptive motion feedback in a one-degree targeted movement task under sighted and non-sighted conditions with the intention of evaluating the ability of artificial proprioception to improve the control of prosthesis. Results suggest the possible benefits of artificial proprioception in upper-limb prostheses.[38]

5. LIMITATION

- None of today's prostheses have purposely designed sensory feedback and proprioception.
- Lack of evidences and clarity regarding which out of body powered and myoelectric prosthesis provides better proprioception and sensory feedback.

6. FUTURE ASPECTS

- Studies need to be done component wise to check proprioception and sensory feedback.
- More studies need to be conducted to compare proprioception and sensory feedback with respect to both body powered and myoelectric prosthesis.

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