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Technical note

A body powered prehensor with variable mechanical advantage

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Abstract

The purpose of this research was to improve body powered, voluntary closing (VC) prosthetic prehension. A prototype prehensor with variable mechanical advantage was fabricated and tested. The device operates at low mechanical advantage during sizing of an object to reduce cable excursion requirements. It shifts to high mechanical advantage during gripping to allow high prehensile forces to be generated with reduced cable tension. The prototype provides a mechanical advantage of 2.4, nearly five times that of conventional VC devices. The prototype also acts as a holding assist; after grip forces are applied, they can be maintained with a cable tension of only 3 lb (13.34N). Field testing indicated that the device performs well in many tasks. The mechanism allows greater range of motion while an object is grasped than standard voluntary closing prehensors. However, the device performed poorly in grasping very compliant objects. To address this problem, a switch has been incorporated into the prototype to allow it to be used in a free-wheel mode.

Introduction

The purpose of a prosthetic prehensor is to replace some of the functions of the hand. Primarily, the prehensor should allow the amputee confidently to grasp and manipulate objects. The ability to maintain grasp is a function of the prehensor shape, the friction between the object and the gripping surface, and the grip force. The purpose of this research has been to improve prosthetic prehension by increasing the amount of grip force that an amputee can generate and maintain.

Upper limb prostheses are most often body powered. Despite advances in externally powered prostheses, body powered prostheses still afford important advantages to the amputee. These include sensory feedback through the harness, lighter weight, lower cost, and quiet, fast operation. One limitation of body powered prehensors is that the grip force is limited by the strength of the amputee. With a conventional body powered harness and cable system, an amputee can typically generate 2 in (5 cm) of cable excursion (Taylor, 1954). To be able to open adequately and close fully with only 2 in (5 cm) of input cable excursion, a conventional body powered prehensor is usually limited to a mechanical advantage of 0.5; 1 lb (4.45 N) of grip force is generated per 2 lb (8.9N) of input cable tension. Most trans-radial amputees can generate 60 lb (266.9N) of cable tension and, therefore, about 30 lb (133.45N) of gripping force with a conventional VC prehensor. Although that is more force than the hand of an adult male can generate in most prehension patterns (Taylor, 1954), those who cannot generate as much cable tension or excursion (trans-humeral amputees, shoulder disarticulation amputees, and amputees using cineplasty) may not achieve adequate grip force

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with currently available body powered devices.

Body powered prehensors can be classified as either voluntary opening (VO) or voluntary closing (VC). VO prehensors, particularly split hook type prehensors, are most widely prescribed. However, there are some important advantages to VC control. In VC control, the cable tension directly generates the gripping force. This allows the amputee better control of the amount of prehension. It also results in more natural feedback patterns: the higher the grip force, the greater the tension on the harness. One major drawback to VC control is that, in order to maintain grip force, cable tension must be maintained. One means of addressing this concern is to provide a lock. VC prehensors incorporating locking devices (e.g. the APRL hook and hand) have not been very successful due to poor reliability and safety concerns. Any locking hand should allow the user to release grip immediately when the need arises. Currently available devices require a conscious effort of the amputee to unlock the prehensor. An alternative to locking devices is the "holding assist", a device that maintains grip forces as cable tension is relaxed yet releases the grip when cable tension approaches zero (Fig. 1). Such a device could alleviate the disadvantages of VC control, yet would be safe and simple to operate. Carlson and Heim (1989) incorporated a holding assist into a VC prehensor. Their design achieved the desired performance, but functioned only briefly due to rapid part wear. A commercially viable holding assist mechanism has yet to be developed.

The variable mechanical advantage prehensor

Grasping is a two stage process: sizing by the fingers to contact an object, followed by generation of grip force. The NU-VA synergetic prehensor decouples these two stages. It incorporates two motors: a high speed, low torque motor for sizing, and a low speed, high torque motor for gripping. Thus, high speed and large grip forces can be achieved in an

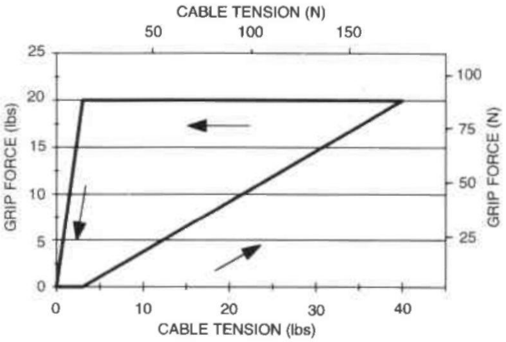

Fig. 1. Idealized gripping performance of a voluntary closing prehensor with a holding assist.

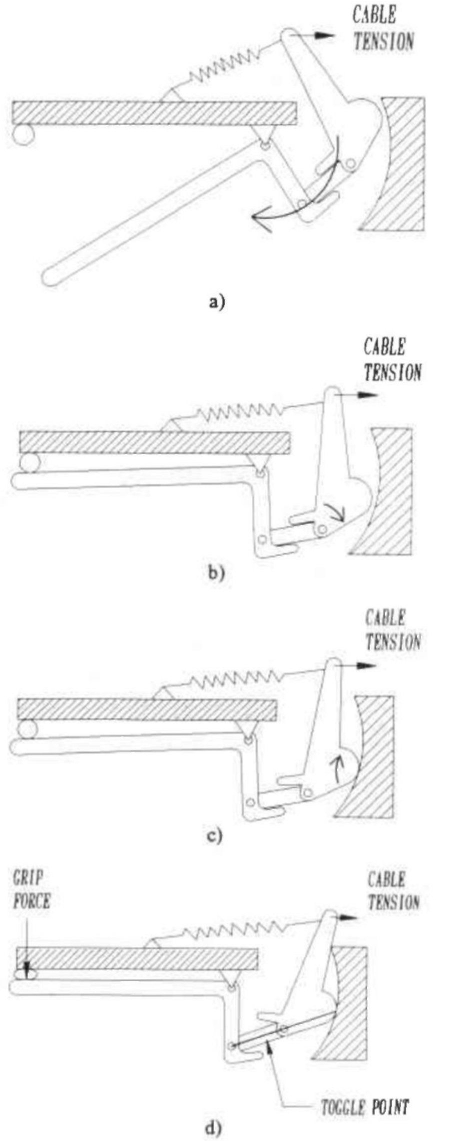

Fig. 2. Operation of the VMA prehensor. a) The VMA prehensor sizing an object. b) When an object is met, the mechanism shifts into high mechanical advantage operation. The input lever comes into contact with a quadrant. c) In high mechanical advantage operation, the lever rolls along the quadrant. d) Finally, the mechanism reaches a toggle point and a holding assist function is activated.

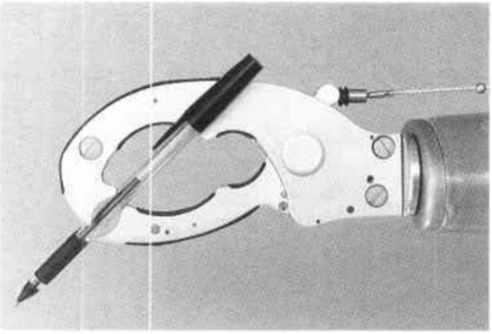

Fig. 3. The VMA prehensor prototype. The button on the side is used to switch between "VMA" and "free-wheel" modes.

externally powered prehensor with reduced energy requirements (Childress and Grahn, 1985).

The Variable Mechanical Advantage (VMA) prehensor applies a similar principle to body powered prostheses. For sizing of an object, it employs low mechanical advantage to reduce cable excursion requirements (Fig. 2a). For generating grip force, it shifts (Fig. 2b) into high mechanical advantage operation (Fig. 2c) to reduce cable tension requirements.

The mechanism was designed to approach the "toggle point", the point at which three joints of the mechanism are aligned (Fig. 2d). At this "toggle point", the mechanism will not transmit forces from the gripping surfaces to the input lever; high gripping forces can be maintained by minimal input cable tension. Thus, a holding assist function was incorporated into the design.

A prototype VMA prehensor (Fig. 3) was fabricated. Its configuration is based on the TRS GRIP[1] prehensor. All of the linkages and springs of the mechanism are hidden from view throughout the range of motion of the device. The gripping surfaces are lined with rubber.

Also included in the prototype was a switch to allow the device to be operated as a conventional, free-wheeling VC prehensor. By pushing a button on the side of the device, the user can lock the mechanism so that the shift into gripping mode cannot occur. Thus, the prototype has two modes of operation: a VMA mode that affords the advantages of the new mechanism, and a free-wheel mode to be used when the properties of the mechanism are not required or desired.

Testing methods

An apparatus was constructed to evaluate the gripping performance of the prototype (Fig. 4). It included a pinch gauge to measure the grip force, a load cell to measure the input cable tension, and a linear variable differential transformer to measure cable excursion.

To perform a test, the pinch gauge was placed at the distal end of the fingers of the prototype. Cable tension was then manually incremented in small, discrete amounts. Gripping performance was also measured as cable tension was manually decreased. For

[1] Available from TRS Inc., Boulder, Colorado, USA.

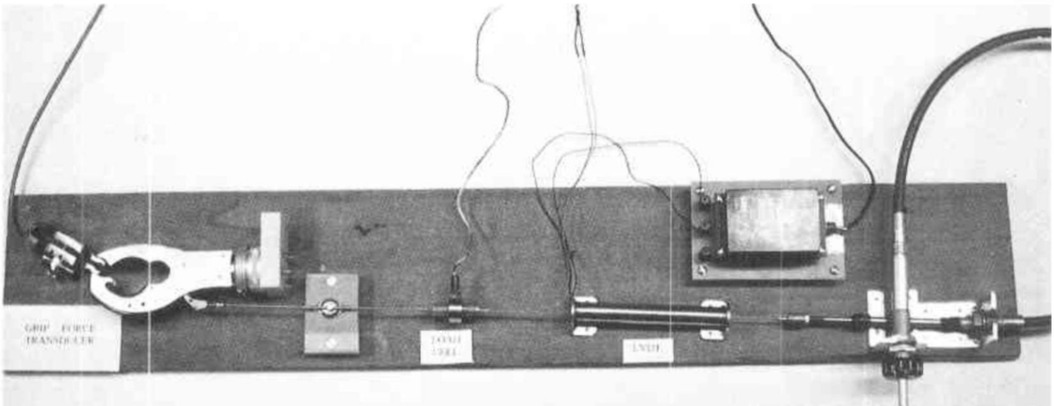

Fig. 4. The grip performance testing apparatus.

comparison, the performance of a standard VC device (The TRS GRIP II) was also measured.

To make an initial evaluation of the practical value of the prototype, field testing was performed. A unilateral, trans-radial amputee wore the prototype prehensor for 20 hours over the course of several days. A variety of common domestic and office tasks was performed with the device. The field tester maintained a log of his activities in which notes on the perceived advantages and drawbacks of the prototype were recorded.

Results and discussion

Figure 5 shows the substantial improvement in gripping performance afforded by the VMA prototype. To generate 20 lb (88.96N) of grip force, the VMA prehensor requires only 8 lb (35.59N) input cable tension, whereas the GRIP II requires about 40 lb (177.93N). The mechanical advantage of the VMA prototype is about five times greater than that cf conventional body powered devices.

As input cable tension to the VMA prehensor is reduced to 3 lb (13.34N), 90% of the generated grip force is maintained. When cable tension is relaxed further, the grip force is reliably released. Thus, the VMA design provides a holding assist function: after grip forces are initially generated, they can be maintained with minimal effort.

Another benefit of the device is illustrated by Figure 6. Here, grip force is plotted as a function of cable excursion rather than cable tension. The slope of the data is a measure of the sensitivity of a prehensor to errors in input cable excursion. The VMA prehensor is about one fifth as sensitive to errors in cable excursion as the GRIP II. The field tester perceived that the VMA prehensor provided an increased "margin of error" in the manipulation of objects. Once an object is grasped, the VMA

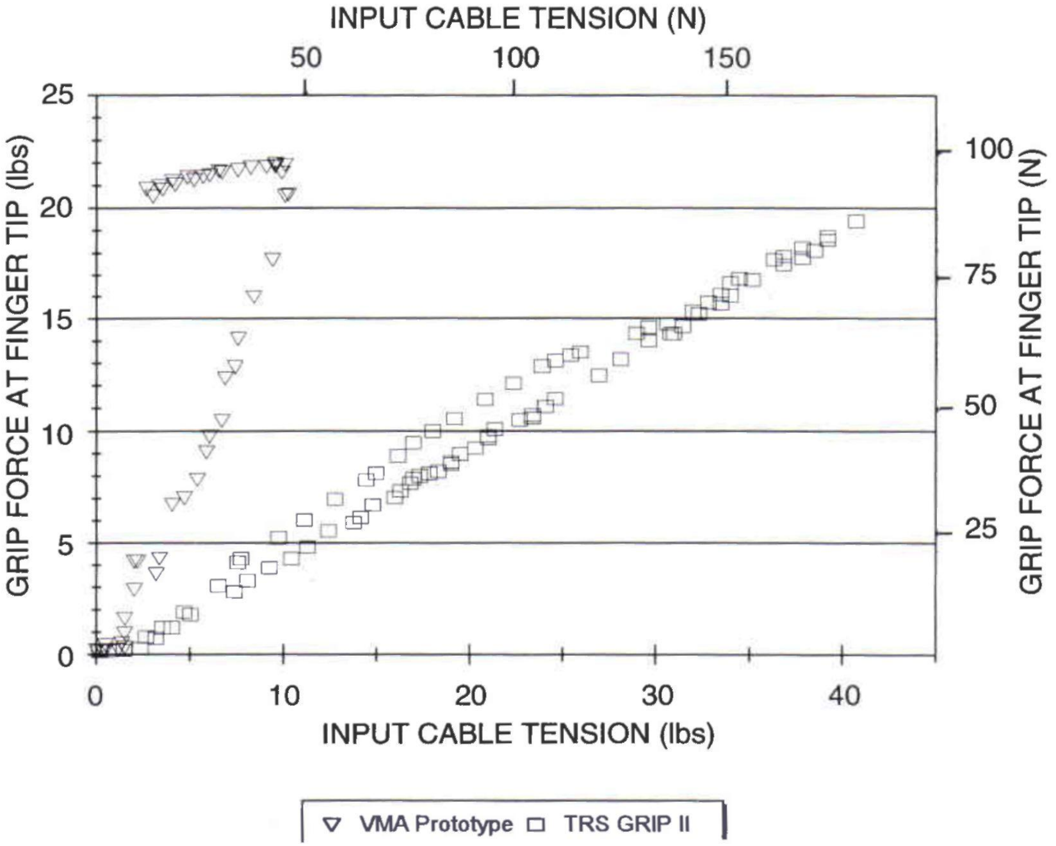

Fig 5 The gripping performance of the VMA prehensor compared to that of a conventional voluntary closing device (the TRS GRIP II).

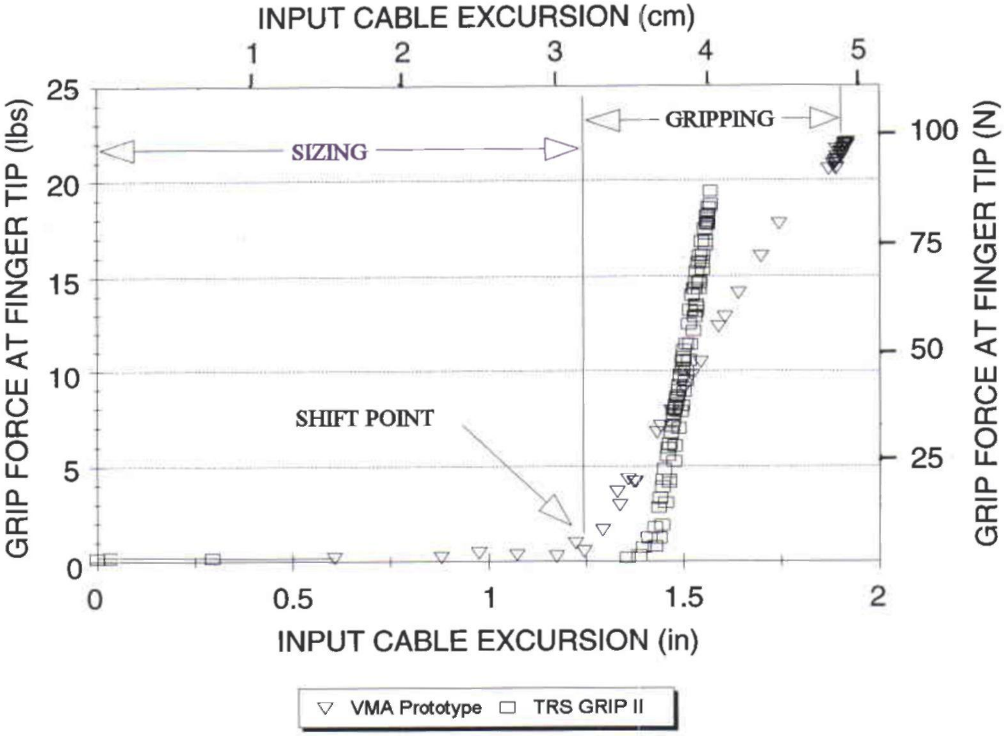

Fig. 6. Sensitivity of the VMA prototype and TRS GRIP II to errors in input cable excursion.

prehensor allows the amputee to move the object without maintaining as rigid a body position as with conventional VC prehensors. This benefit of the prototype was most evident in heavy duty tasks involving gross body movements (e.g. shovelling gravel).

Figure 6 also illustrates that the VMA prehensor requires less cable excursion for sizing, but more cable excursion for gripping than the GRIP II. For relatively compliant objects, this can result in higher overall excursion requirements. In sizing and grasping the pinch gauge, the VMA prototype required 1.90 in (4.83 cm) of cable excursion, while the GRIP II required only 1.55 in (3.94 cm). In field testing, it was noted that the additional cable excursion requirement was occasionally troublesome. For instance, with the prototype in its VMA mode, it was difficult to maintain grasp on objects when held along the side of the body. However, if high mechanical advantage is not required, the free-wheel switch can be engaged. In free-wheel mode, the VMA prototype requires about 37% less cable excursion than the GRIP II. Therefore, the prototype may improve the ability of amputees to maintain grasp in situations in which it is difficult to generate cable excursion.

The most significant limitation of the prototype was its poor performance in grasping very soft objects. After the shift into gripping mode, the mechanism can compress an object by only 1/8 in (0.32 cm). For very soft objects, this amount of compression creates little reaction force. The field tester found that, with the prototype in its VMA mode, he could not confidently grasp objects such as folded towels or rolled newspapers. The free-wheel mode was incorporated to address this concern. In this mode, no problems with handling soft objects is apparent. Also, the button used to switch between modes was found to be easy to access and activate.

Conclusions

Through laboratory and field testing, the prototype VMA prehensor demonstrated some significant advantages over conventional voluntary closing prosthetic prehensors. These include: increased mechanical advantage, a holding assist function, improved amputee mobility while maintaining grip, and reduced cable excursion in free-wheel mode. It has not been demonstrated, however, that these advantages justify the additional complexity and cost of the VMA prehensor design. Clinical evaluation appears to be necessary to explore if and how this device can be of benefit to upper limb amputees. Field evaluation by those who have difficulty in generating adequate cable tension or excursion with body powered prehensors would be of particular value.

Acknowledgments

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