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Upper-Extremity Prosthetics: Considerations and Designs for Sports and Recreation

By Bob Radocy

The population of upper-extremity amputees, including congenitally limb-deficient persons, in the United States and abroad is placing increased demand upon the profession for improved prosthetic designs and devices which will allow its members to participate competitively in sports and recreation activities.[1,2,3] Recreation trends indicate that these demands will most likely increase.

Until recently, prosthetics did not directly address the needs of the sports-oriented amputee. Prosthetic designs focused on domestic and vocational needs and did not necessarily target the criteria necessary to perform in the vigorous environments of sports or recreation. Over the years, select prosthetists working with individual amputees have developed "one of a kind" sports devices for their patients. These devices sometimes proved adequate, but most were never made available commercially.

Two commercially available sports terminal devices have been available for many years: the Baseball Glove Attachment and the Bowling Attachment.[4] Recently, other specialized prosthetic devices have become available to meet the sports-minded amputee's needs. These are the SUPER SPORTs,[5] Amputee Golf Grip,[6] and the Ski Hand.[4] Additionally, new variations in the designs of body-powered terminal devices are allowing amputees to participate in many sports activities without the need for specialized aids or radical modifications.[7,8]

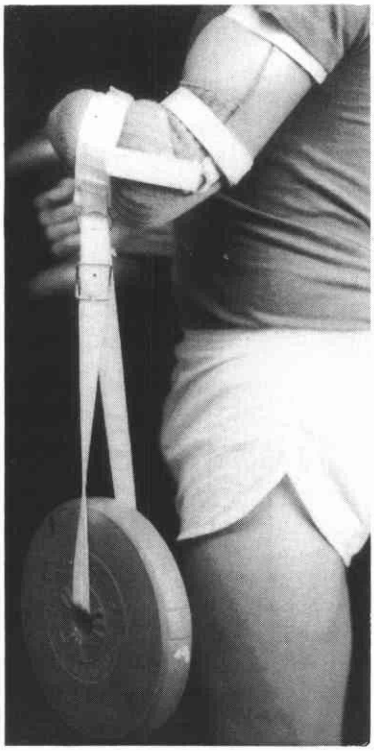
The measure of performance by the amputee in any activity, as always, depends upon proper limb design. Socket design, materials, alignment, and components all play a vital role in any amputee's ability to perform competitively. Another important factor is the amputee's physical condition. The prosthesis, no matter how well designed and constructed, cannot supplement atrophied muscle, limited range of motion, or inadequate strength.

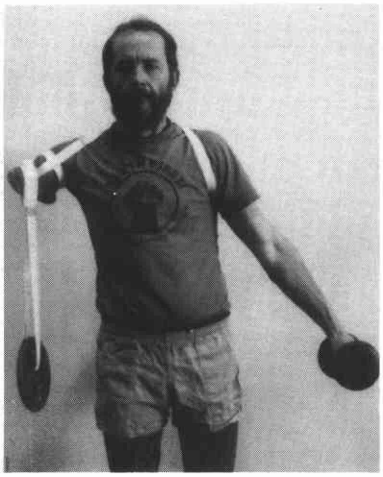
Sports prosthetics begins with the evaluation of the need and of the capacity of the amputee being served. A physical therapist and potentially a clinic physician will be important components in the rehabilitation of an amputee wishing to become active in sports and recreation.

Exercise and conditioning with or without a prosthesis will be required as a preliminary step for an amputee who wishes to excel without injury in sports. Exercise can take multiple forms. Proven exercise techniques exist. Isometric, isotonic, and passive and active resistance all have specific goals and methods. Education is required so that the amputee is knowledgeable about how to proceed with an exercise program and to determine the objectives, i.e. is muscle hypertrophy (bulk) required for strength or is muscle endurance more appropriate? Additionally, how are flexibility and range of motion impacted?

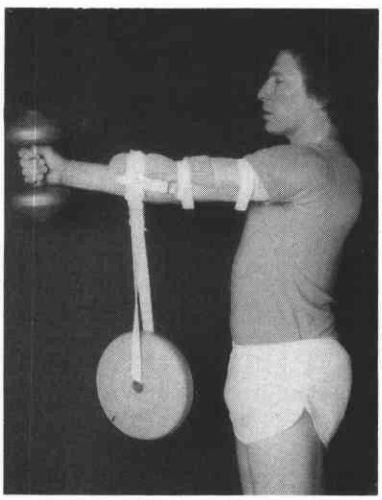
Preprosthetic exercise may be required or desired. Weight harnesses[9] (Figures 1, 2, and 3) rather than strap or cuff weights are a better way to approach exercise without a prosthesis. A properly designed harness will prevent weight slippage during exercise and will enable many variations of upper-extremity conditioning (Figures 4, 5, and 6).

Bilateral exercise using a dumbbell on the non-affected side is important to maintain muscle balance and reduce spinal stress. A full

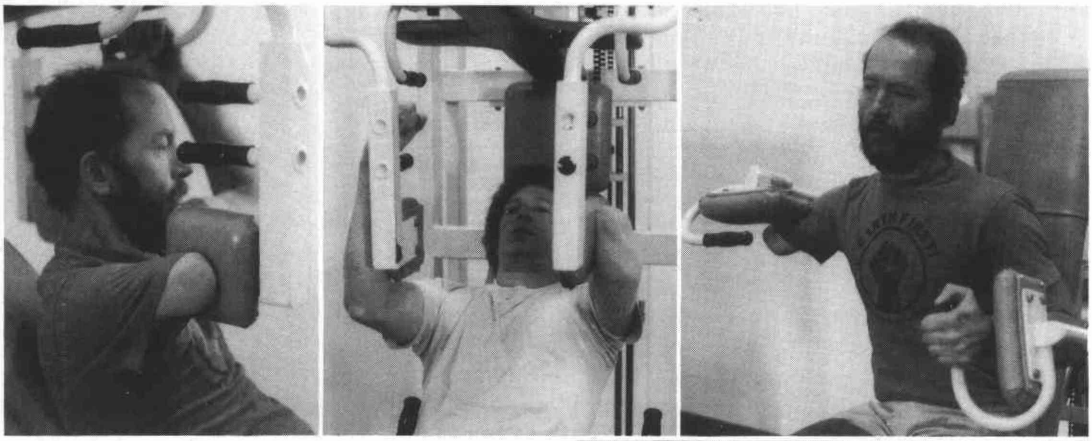




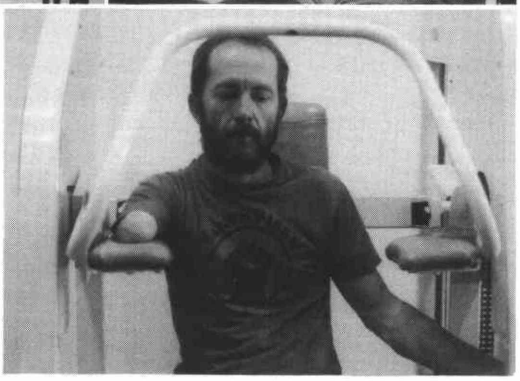
Figures 1, 2, and 3. Weight harnesses, rather than strap or cuff weights, are a better way to approach exercise without a prosthesis.



Figures 4, 5, and 6. A properly designed harness will prevent slippage during exercise and will enable many variations of upper extremity conditioning.



Figures 7, 8, 9, (above) and 10 (right). Certain weight machines also allow for non-prosthetic exercise, but exercise will be limited to certain muscle groups.



length mirror aids the amputee in viewing him or herself in order to correct postural deficiencies or extraneous movements to optimize resistance exercise efforts.

Certain weight machines also allow for non-prosthetic exercise, but exercise will be limited to specific muscle groups (Figures 7, 8, 9, and 10). Complete upper-body conditioning will be most effectively accomplished while wearing a prosthesis. Furthermore, exercise while wearing a prosthesis will help condition the residual limb to the skin stresses and shears a prosthesis will create when under load. Modern exercise equipment systems, such as Nautilus, Hydra-Fitness, and Universal, are available virtually everywhere in YMCAs, community recreation centers, health and sports clubs. A planned program for the amputee can be structured by professional instructors to the amputee's goals. Free weights are another alternative or can complement a weight conditioning program with the convenience of low cost and home use. Equipped with a proper terminal device (Figure 11), an arm amputee can safely handle dumbbells or barbells in weight training.

Proper conditioning balanced by flexibility achieved through passive stretching, aerobics or any number of alternatives will result in the range of motion and strength an amputee will need for high performance in sports and recreation. A regular conditioning program will

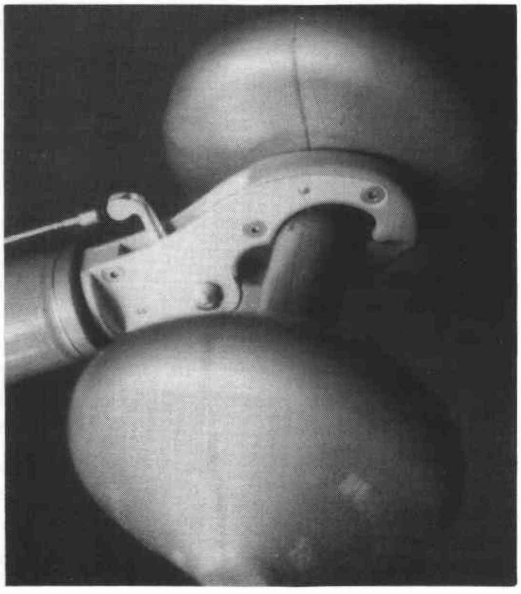


Figure 11. Amputee lifting dumbbell with a terminal device.

especially enhance the use of body-powered prostheses which require activation through body-controlled movements.

Sound limb design, mentioned previously, is a major component in an amputee's performance potential. Lightweight yet strong prostheses are ideal, but strength should not be sacrificed just to achieve reduced weight. Socket design is dictated to a certain extent by stump configuration, but it is the author's belief that, if at all possible, a supra-condylar socket should be used.[10,11] Supra-condylar sockets with all their variations (Muenster, Bock, etc.) have evolved rapidly with advances in electromechanical limbs. A supra-condylar socket need not be unduly restrictive, and such a limb allows for less complicated harnessing.

Carbon fiber and acrylic resins are two materials which lend well to the lightweight but high strength prosthetic objectives. Socket padding,[10] whether fully or partially lined, aids in protecting the condyles, olecranon, and distal residual limb end from trauma. If adequately reinforced, ISNY[12] style sockets may prove to be applicable for sports as well, but the published data on below-elbow applications is scarce.

In addition to padding, the author recommends a heavy residual limb sock or two regular weight socks for most sports activities. Highly absorbent terry lined socks (designed for athletic footwear) are excellent. A polypropylene sock can be used effectively as a liner if heavy perspiration is a problem.

An adjustable excursion harness,[13] such as the modified Northwestern (Figure 9) which allows for excellent range of motion and terminal device control, can be applied, although other designs will work. Rapidly adjustable excursion is a plus for actuation of voluntary closing terminal device systems and in sports where gross motion of the arms is required, i.e. archery, golf, baseball, etc. Cable efficiency may also be targeted for consideration. Several experienced amputees known to the author wax the stainless steel cables before assembly into the cable housing. The wax is clean and reduces cable to cable housing friction, thus improving efficiency.

Alignment of the prosthesis on the residual limb also requires consideration, depending upon the amputee's sports needs. Preextended, as opposed to preflexed, socket designs have

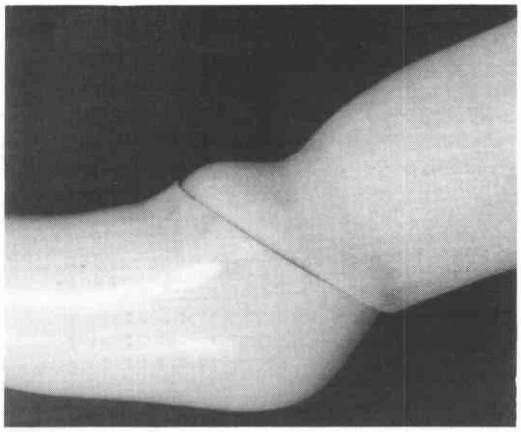


Figure 12. A supra-condylar fit socket with an undesirable trim line.

useful applications in sports. They allow for full elbow extension while limiting flexion only slightly and usually not unacceptably. Wrist alignment is also of consequence and affects the manner in which the prosthesis torques on the residual limb when load is applied. It is important to emphasize the need for prosthetists to be concerned with dynamic forces on the prosthesis. A mere static fitting with a check socket will not suffice because it doesn't accurately duplicate what will occur in the definitive prosthesis. A secondary fitting session with a foamed, but unlaminated, prosthesis donned and the chosen wrist unit and terminal device in place can determine the optimum alignment of the components. Changes can be made accordingly and retested so that the definitive prosthesis will fit correctly. Testing the prosthesis in this manner will also determine if undesirable trim lines exist in the socket or whether extended padding is required. A supra-condylar fit socket on short residual limbs can cantilever on the epicondyles and cut in proximal to the olecranon when the prosthesis is loaded distally making it impossible to carry any significant load (Figure 12). Extending the trim line can direct pressures to the back of the humerus instead of into the joint.

Two other techniques which can aid in creating a more suitable sports prosthesis are external padding and suspension sleeves. Nylon covered neoprene rubber, such as a diver's wet suit material, is readily available and makes an excellent "stretch to fit" cover for a prosthesis (Figure 13). Thicknesses from

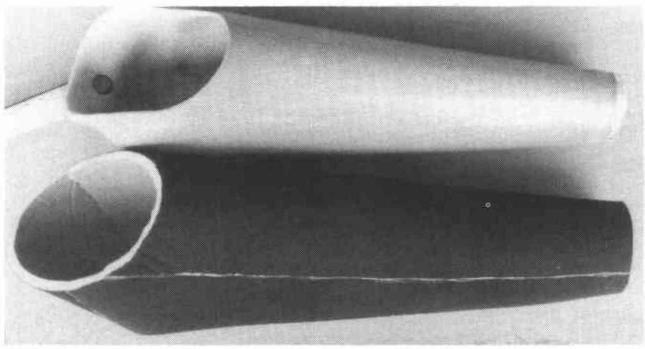


Figure 13. Nylon covered neoprene rubber, such as a diver's wet suit material, is readily available and makes an excellent "stretch to fit" cover for a prosthesis.

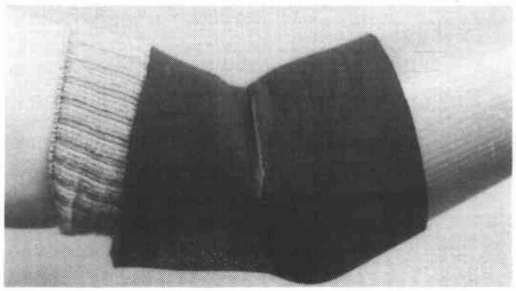


Figure 14. Both latex and neoprene sleeves designed for below-knee amputees are available and can be modified for upper extremity use.

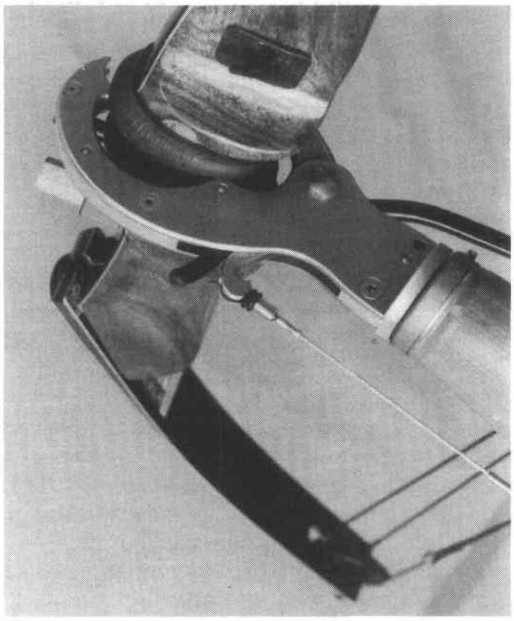


Figure 15. A bow riser (handle) can be modified to create a functional bow grip.

3 mm to ¼" are available. The material provides a good cushion for contact sports, helps reduce limb trauma during a fall, and the thicker materials have enough bouyancy to float a prosthesis. This technique has satisfied the requirements for a padded prosthesis in several school systems around the country.

Suspension sleeves can improve a supra-condylar fit, especially when using a passive recreational device where the cable is absent or does not play a role in prosthetic suspension. Both latex and neoprene sleeves designed for below-knee amputees are available and can be modified for upper-extremity use simply by cutting them down in length (Figure 14). The advantages of using a commercially available below-knee sleeve is that angulation for a joint is already built in. The author prefers neoprene due to its durability. Both cause increased perspiration within the socket. Designed properly, a neoprene prosthetic cover can function as a suspension sleeve as well.

The remainder of this article will focus on modifications for specific sports and recreation to which the author has been exposed either directly or indirectly. In some cases, the solutions are simple; in others, performance dictates a more complex technical solution. Photographs and drawings have been used as often as possible rather than the written descriptions to illustrate a modification, device, or technique. Activities are dealt with alphabetically for convenience sake.

Archery

Modern archery equipment is easily adaptable to certain types of terminal devices. Figure 15 illustrates how a bow riser (handle) can be wrapped with consecutive layers of rubber,

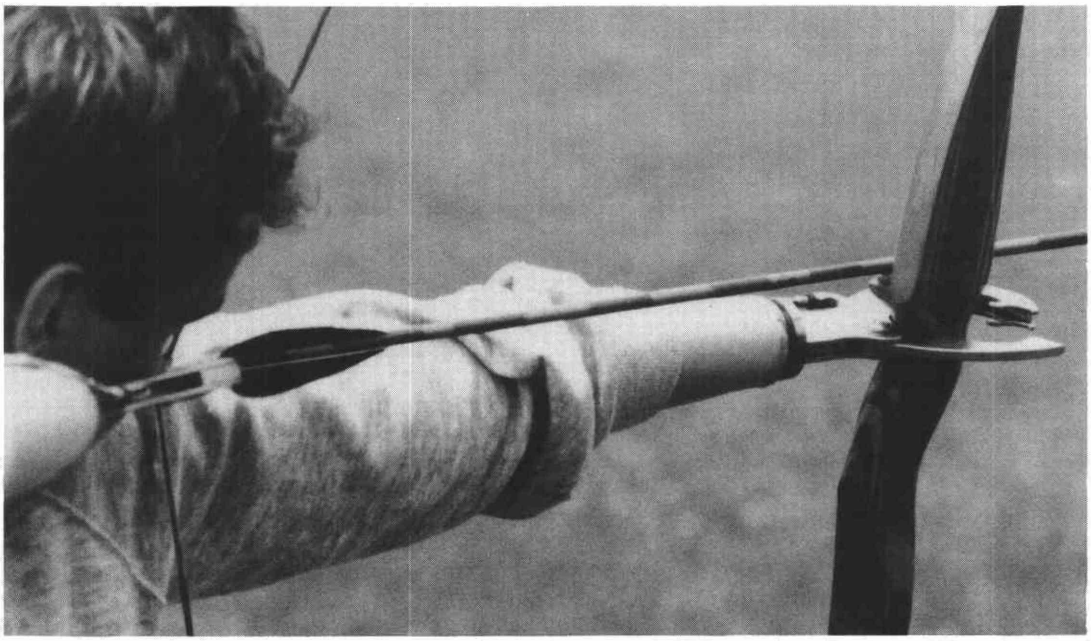


Figure 16. An amputee can simply hold on to the bow as shown.

foam, and bicycle inner tube to create a durable, functional bow grip.[8] A chuck or pin can be used to jam the thumb of the terminal device closed around the riser or the amputee can just "hold on" as illustrated by Figure 16.[14] Performance capabilities are exemplified by the amputee archer in this photo. He is a skilled hunter who has harvested three deer in a four year period.

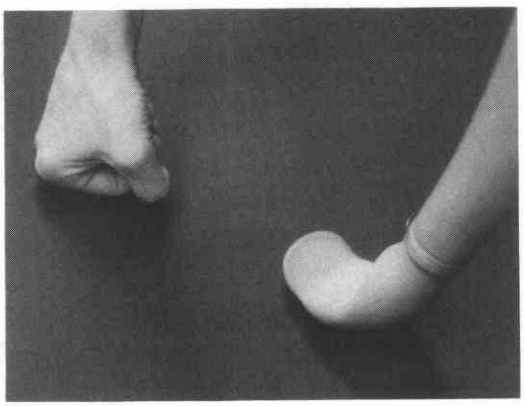
Basketball, Soccer, Volleyball, and Football

Until recently, aids for amputees in ballsports were limited to padded hooks, cosmetic hands, and custom one-of-a-kind terminal devices. Although these devices were useful, they rarely provided the type of high performance characteristics the sports-minded amputee required to compete successfully.

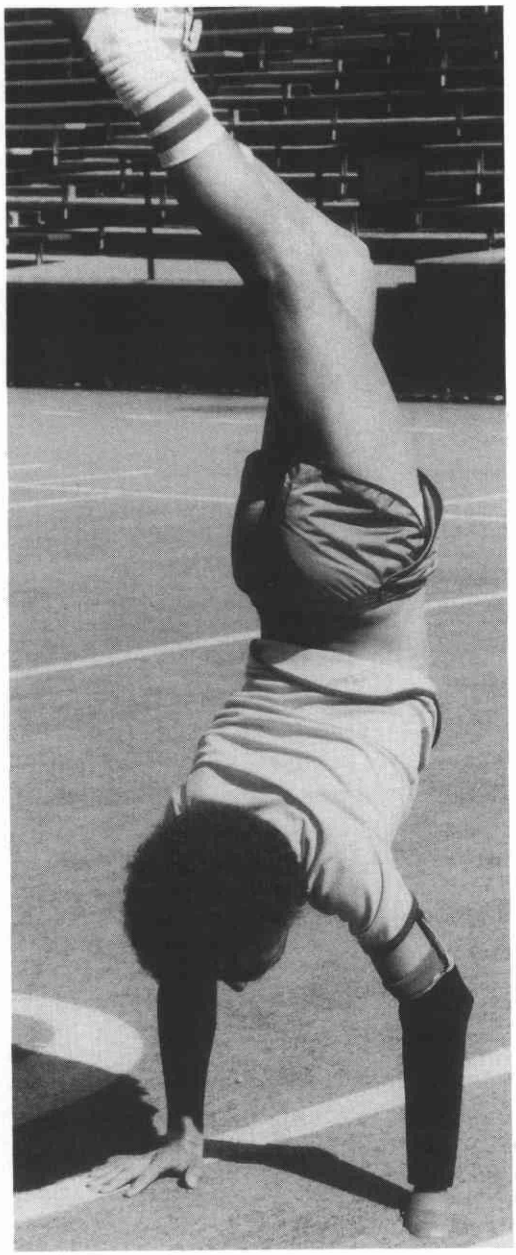
One possible answer or solution is now available. The SUPER SPORTs devices, sized for all ages, are designed specifically for ballsports and other rigorous recreations in which hand/wrist flexion/extension is needed. Additionally, they absorb shock as well as store and release externally applied energy (Figures 17, 18, and 19). SUPER SPORTs are passive, not cable activated, but are helpful in catching and ball control when used in opposition to an anatomical hand or another device. SUPER SPORTs combined with padded arm covers create a safe, effective prosthesis for sports, such as football, basketball, and soccer in which interpersonal contact is inevitable.

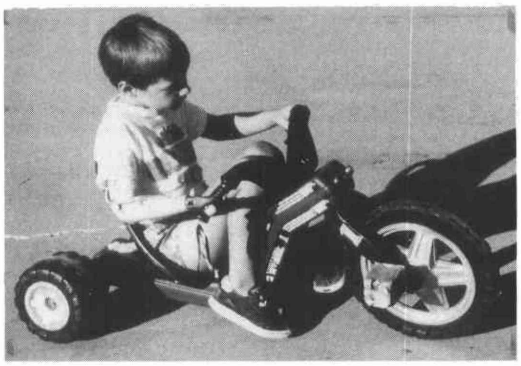
Bicycling, Tricycling, and Motorcycling

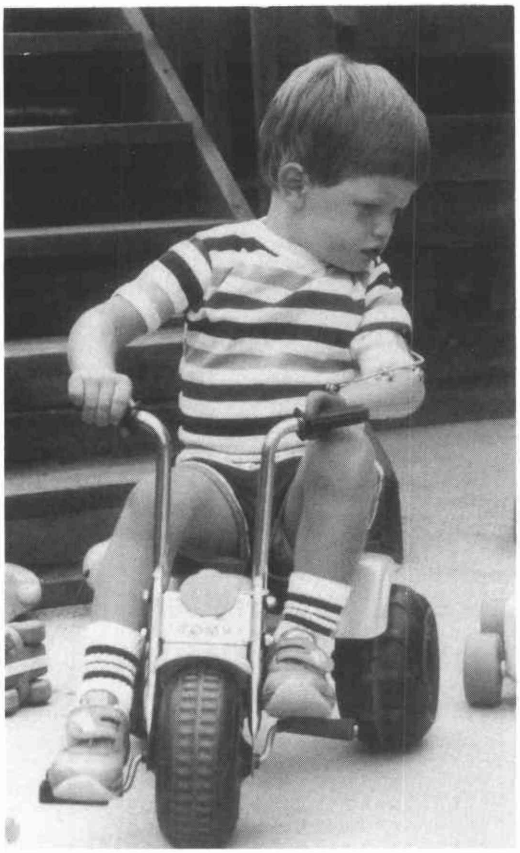
Bicycling or tricycling has proven to be an aggravation for amputees equipped with conventional style hooks. Lack of adequate gripping strength and finger shapes have hampered performance. Presently, however, children and adults equipped with newer style voluntary closing terminal devices (Figures 20 and 21) can control two or three wheeled cycles as well as their two-handed peers. No modifications are required except when hand brakes are present. Front and rear brakes can be actuated from a single hand lever. Brake pressure must be regulated so that braking forces are always applied to the rear wheel first for safe handling. Your local bicycle shop can usually solve hand brake complications.



Figures 17, 18 and 19. The SUPER SPORTs devices sized for all ages, designed specifically for ball sports and other rigorous recreations in which hand/wrist flexion/extension is needed.







Figures 20 and 21. Children and adults equipped with newer style voluntary closing devices can control two or three wheeled cycles as well as their two handed peers.

Special adapters have been designed for or by individuals interested in competitive bicycle racing (Figure 22).[15] The prototype illustrated is simple and is designed for safety to "quick disconnect" or "break away" at certain levels of force.

Motorcycling is a natural extension of bicycling. Again, hand brakes and, in this case, a clutch hand lever complicate the situation. Unilateral amputees missing their left hands can shift and clutch with one hand with practice. Brakes again can be combined. A single foot lever is practical for driving dual master cylinders for hydraulic brakes. The rear wheel braking must occur first however. A local motorcycle mechanic or custom motorcycle shop can provide ideas or adaptations and modifications to standard equipment.

Canoeing and Kayaking

The author's experience with conventional terminal devices proved frustrating during these types of recreation. Split hook finger shapes did not adequately adapt to a paddle or oar. Lack of prehension inhibited the bilateral arm function required for these activities. Locking type terminal devices should *never* be used in water sports activities. Figures 23 and 24 illustrate how new technology and minor modifications to paddles can overcome problems in canoeing.

Kayaking (Figure 25) with a double-bladed paddle requires only coordination and practice. Rubber rings on the paddle which are used to keep water off the central shaft work equally well in preventing terminal device slippage.

Gross arm movements, such as paddling or rowing, inherently activate voluntary closing devices and keep them closed. Rowing using an oar and oar lock can be enhanced by adding a stop or flange to the oar handle to prevent the terminal device from inadvertently pulling off during a power stroke.

Dance/Floor Exercise and Gymnastics/Tumbling

Activities, such as dance, tumbling and floor exercise gymnastics, have been treated similarly to ball sports in the past due to a lack of specialized terminal devices that were readily available. Padded hooks, cosmetic hands and

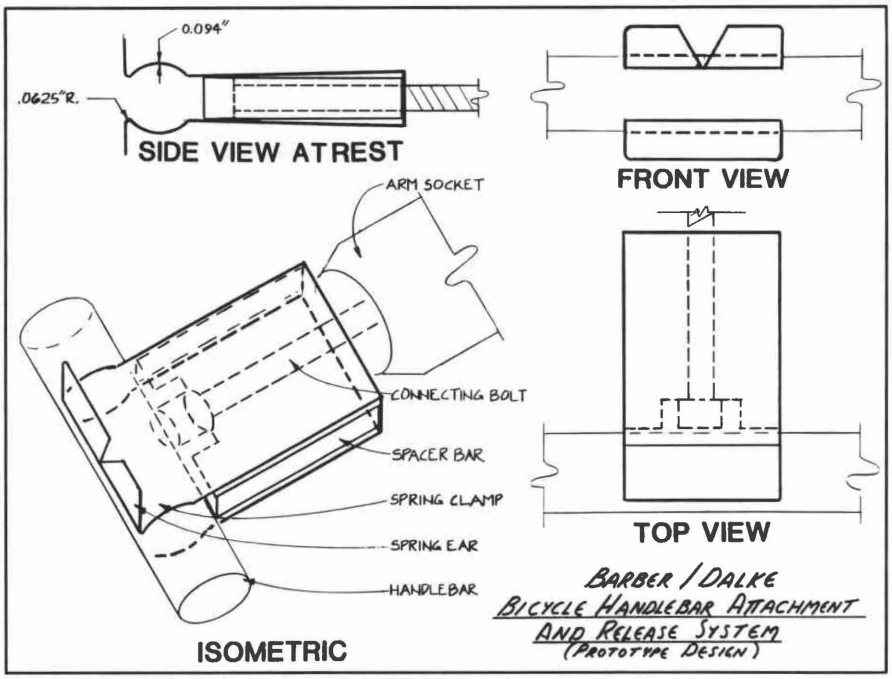
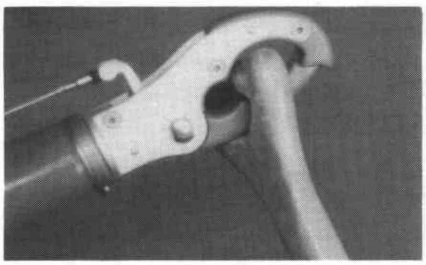
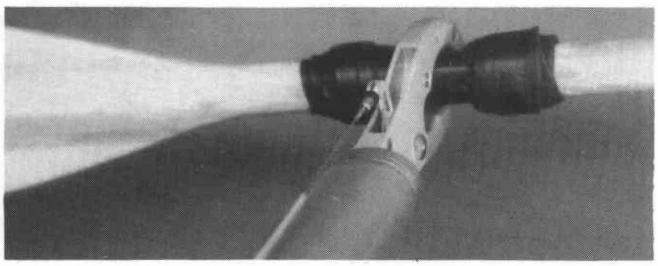


Figure 22. Special adapter for use in bicycle racing.





Figures 23 and 24. New technology and minor modifications to paddles can overcome problems in canoeing.

some custom pedestal style terminal devices have been applied to attempt to satisfy the amputees' needs for balanced bilateral function. Figure 26 illustrates how the SUPER SPORT terminal devices can be applied to satisfy these specialized recreation niches.

Fishing

Fishing is a sport and pastime everyone has access to and should be able to enjoy. Amputees using split hooks who wish to have improved control of reels might want to consider the Ampo Fisher I[16] which adapts to their prosthesis and reel (Figure 27).

Another alternative for the high level amputee is the Royal Bee Electric Retrieve Fishing Reel system (Figure 28).[17]

Amputees equipped with voluntary closing terminal devices do not require many modifications to fish. A handle modified with some rubber inner tube or tape is usually all that is required to operate a spinning or bait casting reel, due to the improved prehension of these types of terminal devices (Figures 29 and 30).

Casting with a prosthesis is awkward due to lack of wrist flexibility. Amputees usually control the pole with their natural hand then switch hands to reel or reel with the terminal device. Most reels are available in left and right handed models to suit various physical conditions.

Figure 25. Kayaking with a double-bladed paddle requires only coordination and practice.

Figure 26. SUPER SPORT terminal devices can be applied to satisfy specialized recreation niches.

Figure 27. Amputees using split hooks may want to consider the Ampo Fisher I which adapts to their prosthesis and reel.

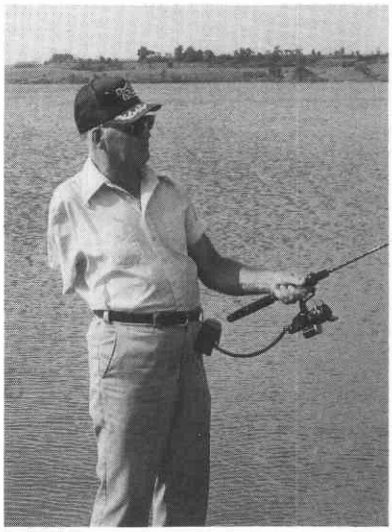
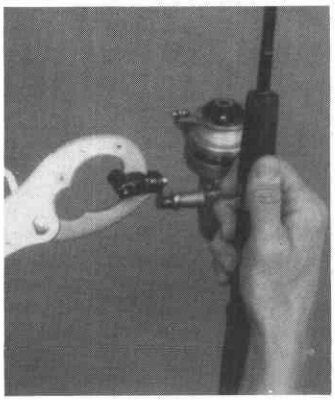
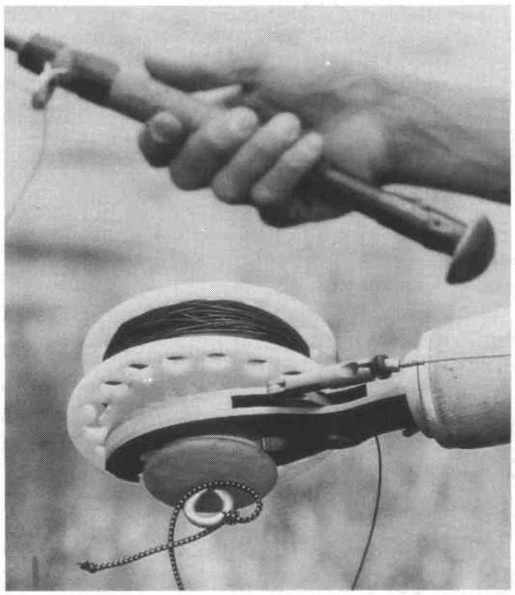
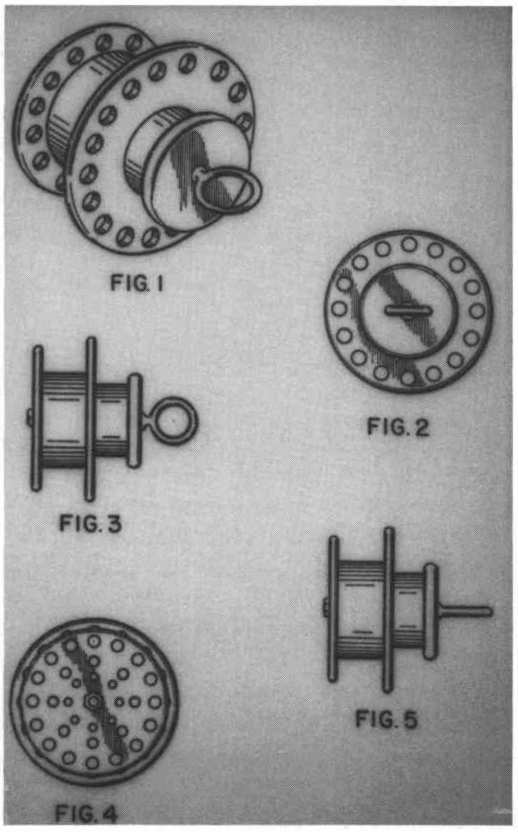


Figure 28 (above). The Royal Bee Electric Retrieve Fishing Reel systems.



Figures 29 and 30 (left). A handle modified with some rubber inner tube or tape is usually all that is required to operate a spinning or bait casting reel.





Figures 31 and 32. The Fly Fishing Reel for Amputees.

Fly fishing poses more of a challenge due to the two-handed dexterity required in handling the fly line. One alternative is the Fly Fishing Reel for Amputees[5] (Figures 31 and 32). This system has been used successfully, although the author feels there is still a need for improved alternatives.

Automatic fly reels have been experimented with unsuccessfully due to the difficulties involved in "pulling out line" to wind up the return spring in these reels. Additionally, it was discovered that the spring force was only sufficient to pull in slack line, not with line under drag or a fish engaged.

Golf

Due to its popularity, golf has rules (USGA 14-3/15) regarding artificial limbs established by U.S. Golfing Association for tournament play.

Variations in golf aids have evolved over the years primarily as individual designs to suit specific amputee's needs. Recently, however, a device called the Amputee Golf Grip (AGG)[6] has been introduced. The AGG is a standardized manufactured product which meets the USGA requirements (Figures 33 and 34). The device is somewhat similar to the Robin-Aids Golfing device[18] (Figures 35 and 36). Both devices utilize a flexible member to attach to the prosthesis and do not require club modification. They allow for *complete* wrist/club flexion and extension. The Amputee Golf Grip also allows for unrestricted rotation.

Other attempts to produce a functional aid should also be noted. One custom device is designed to have clubs attach directly to the prosthesis (Figure 37).[19] Similarly, another model, the Atkins Golf Aid,[20] also attaches into the end of the club, but uses a ball-socket swivel. The swivel allows for a limited degree of wrist/club, flexion/extension, and complete rotation.

The author has tried several devices and prefers those that do not require club modification and which provide for total flexion/extension/rotation at the wrist/club interface. This allows for a complete back swing and smooth follow through capability.

Figures 33 and 34. The Amputee Golf Grip is a standardized manufactured product which meets the USGA requirements.

Figures 35 and 36. The Robin-Aids golfing device.

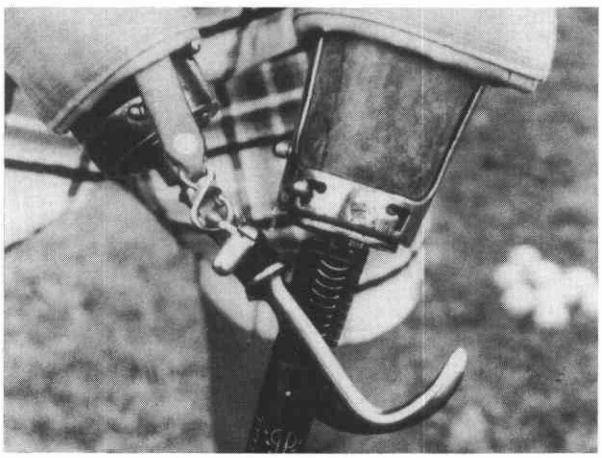


Figure 37. A custom device designed to have clubs attach directly to the prosthesis.

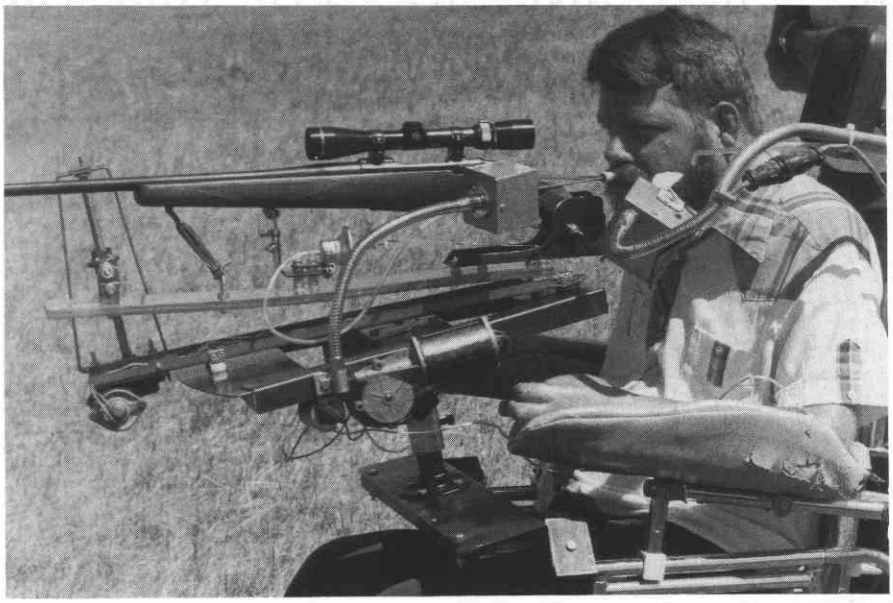


Figure 42. The SR-77.

Figure 43 (right). The Para-Quad shooting system.

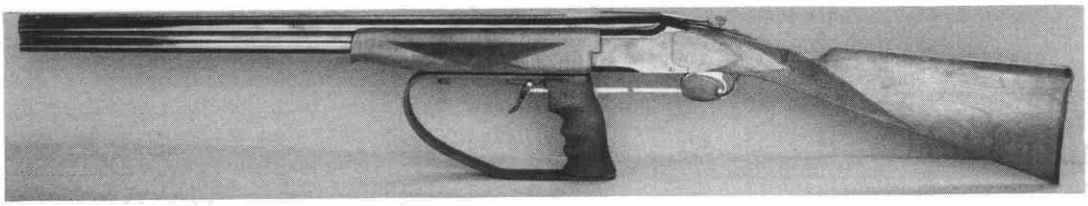


Figure 44. An over and under shotgun modified to shoot one-handed.

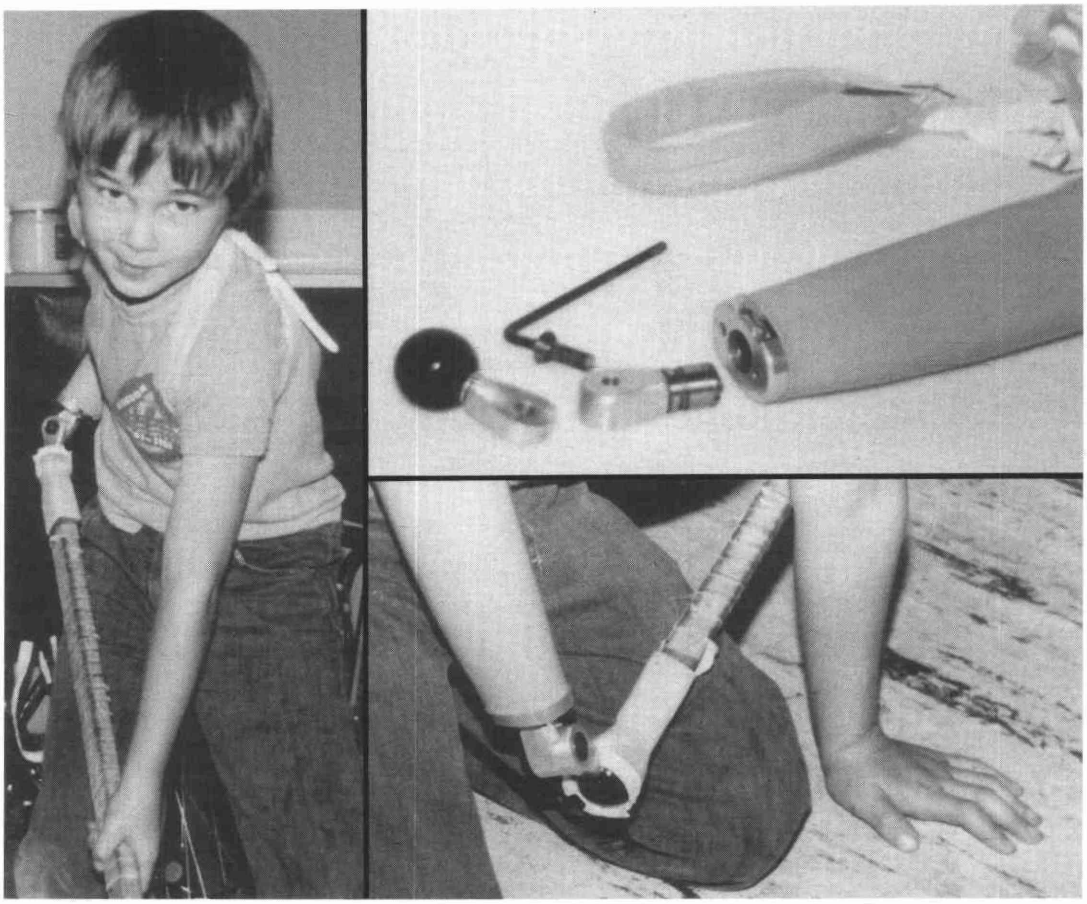


Figure 45. A terminal device for hockey developed in Canada.

Music

Information and devices to aid amputees playing instruments is scarce. Recently, however, information on a new guitar prosthesis was published in Canada[19] (Figure 48). Dan Roy, the guitarist, in conjunction with specialist Armand Viau have developed a prosthesis which allows Roy to use his shoulder to strum the guitar. The arm is lighter than a conventional prosthesis and can hold a guitar pick.

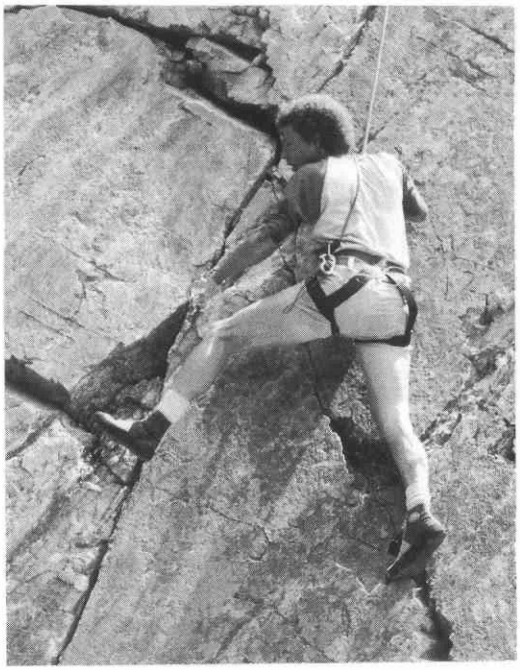
Figures 49 and 50 illustrate how some newer terminal devices, such as the ADEPT,[5] have proved to be viable solutions for children wishing to "play" musician.

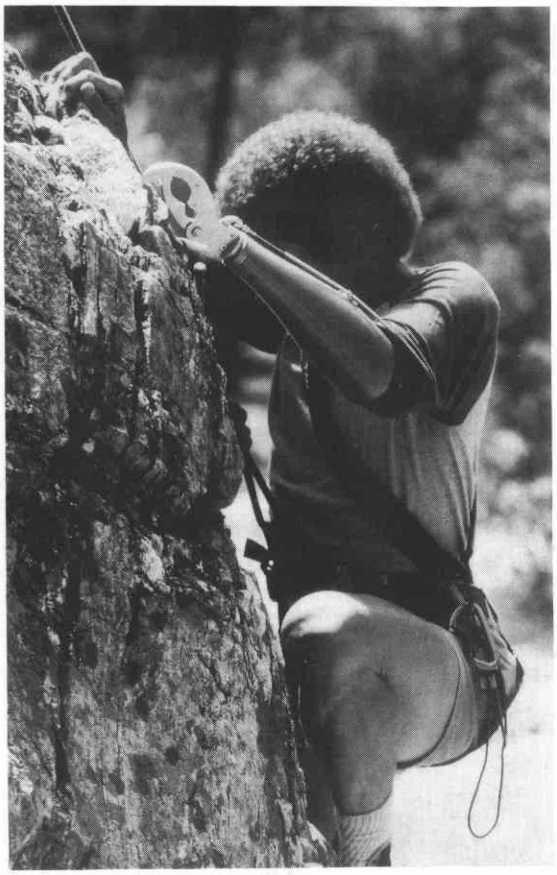
Photography

Custom photography and camera adapters have been fabricated for years. Now a device called the Amp-u-Pod[5] (Figure 51) is a standardized, manufactured product which has proved to be an extremely effective aid for the amputee photographer. Designed to replace the amputee's regular terminal device, the Amp-u-Pod mounts directly to the prosthesis and adapts to any 35mm, movie, or video camera equipped to receive a tripod.

Sailing

Amputees are less restricted in this recreation, but handling rope lines and other types of sailing gear can place demands on the sailor to have two-handed capabilities. Figure 52[22] illustrates a triple amputee who found a GRIP[5] terminal device to be one of his best assets for sailing.





Figures 46 and 47. The author during a technical climbing training session.

Figure 48. A new prosthesis which enables guitarists to strum their instrument using their shoulders.

Figures 49 and 50. Newer terminal devices, such as the ADEPT, have proved to be viable solutions for children wishing to "play" musician.

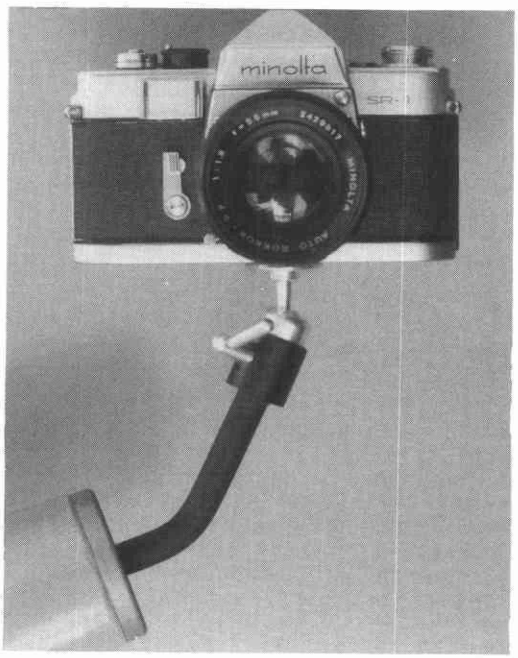


Figure 51. The Amp-u-Pod has proven to be extremely effective for amputee photographers.

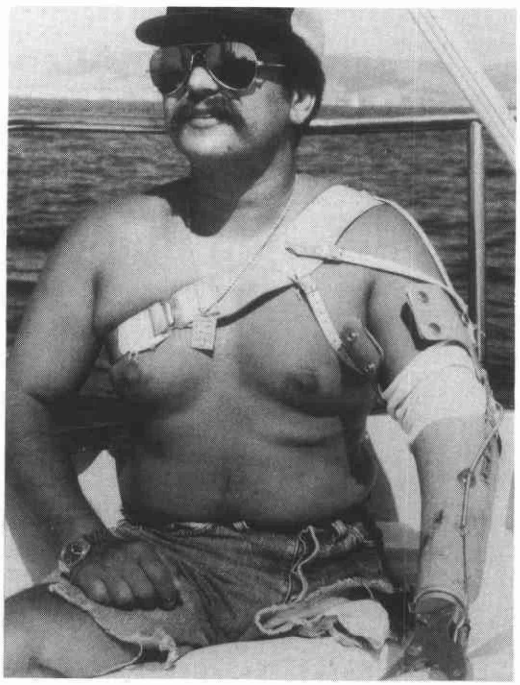


Figure 52. A GRIP terminal device used for sailing.

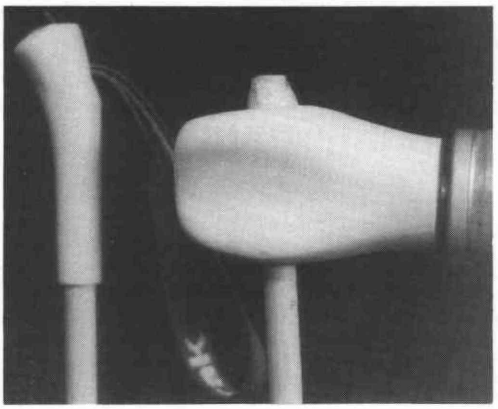


Figure 53. The Ski Hand.

Snow Skiing

Amputees have experimented with a number of ways to attach a ski pole to a prosthesis with little functional success. The Ski Hand[4] (Figure 53) is the first standardized manufactured terminal device designed specifically for skiing. Available in varying sizes, the amputee force fits the Ski Hand over a ski pole after removing the standard hand grip. The Ski Hand proved worthwhile for cross-country skiing where upper-body strength is required for propulsion. During downhill skiing, the author found the device of less advantage due to the shallow angle to which the pole enters the hand. The pole basket had a tendency to drag in the snow and was therefore more difficult to control. Novice skiers, however, will find the Ski Hand useful because it enhances maintaining balance and getting up after a tumble.

Swimming

Swimming for many upper-limb amputees requires no aid whatsoever. However, for those individuals who wish to perform better or compete in the water, several devices have evolved as custom, one-of-a-kind solutions. The Viau-Whiteside Swimming Attachment[19] (Figure 54) and the P.O.S.O.S./Tablada Swimming Hand Prosthesis[23] (Figures 55 and 56) are two with which the author is most familiar, although others may exist.

The Tablada hand is flat rather than curved to prevent submarining of the prosthesis during pre-stroke arm extension (Australian Crawl) in order to generate greater stroke volume. Additionally, note that the Tablada system uses a prosthesis which is close to actual anatomical arm length, whereas the Viau system has a shortened forearm section. Both utilize a preflexed, rigid elbow design. The Viau arm was designed primarily for back stroke swimming and may therefore account for the curved terminal device shape which would not hamper this style of swimming.

The author is also aware of the use of SUPER SPORT devices for swimming, especially for children unaccustomed to the water.

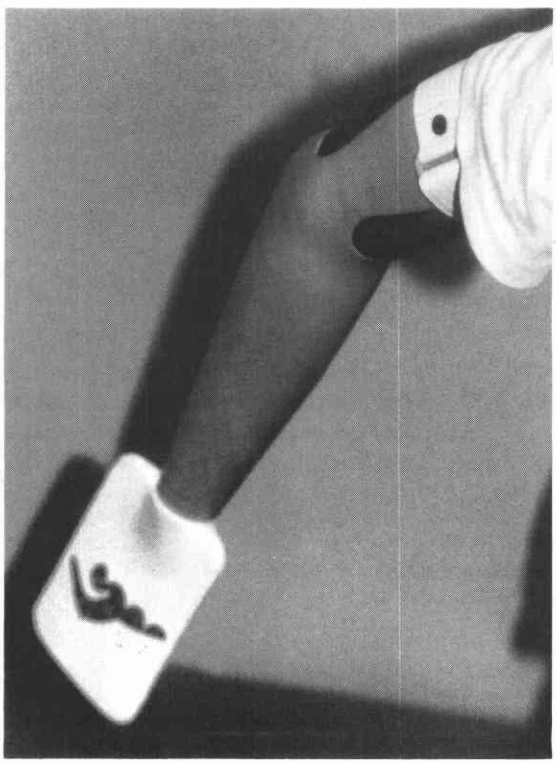
Pistoning of the prosthesis can be one of the most common occurrences during swimming. A suspension sleeve can aid in eliminating this action. An additional consideration related to swimming and skin or scuba diving is that the prosthesis is not as buoyant as the body and can seem heavier than normal in water and sometimes will impair performance.

Water-Skiing

Water-skiing can be an extremely dangerous recreation if not approached with caution. The author suggests the following rules of good judgment if water-skiing is on an amputee's wish list of recreational pursuits. First, don't ever lock onto a ski rope handle with any terminal device or use a terminal device which requires a cable and harness system. Second, use a ski rope equipped with a single handle. Third, wear a self-suspending, condylar socket that can be twisted free of under stress. A suspension sleeve will aid support but not impair release of the socket due to the flexibility of the material. Fourth, have a neoprene arm cover for the prosthesis which will float the arm in the water if it comes off. Fifth, *always* wear an approved floatation vest.

The Water Ski Hook[5] (Figure 57) is a simple solution to water skiing that has proved safe when set up and used properly. The Ski Hook should be mounted on the prosthesis in a canted position and tightened into place so that it cannot rotate freely. The shallow hook design provides support, yet will twist off a ski rope handle. Should a fall occur where twisting off is impaired, the supra-condylar socket can be "torqued off" the arm and save the amputee's shoulder from potential trauma.

Figure 54. The Viau-Whiteside swimming attachment.



Figures 55 and 56. The P.O.S.O.S./Tablada Swimming Hand Prosthesis.

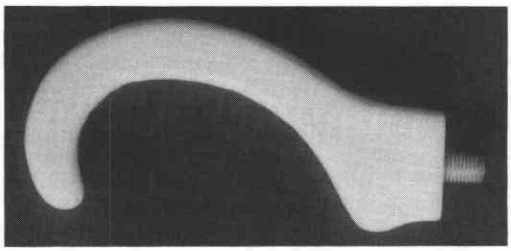


Figure 57. The Water Ski Hand is a simple solution to waterskiing problems.

Another solution to prevent injury is to have the tow rope attached to the boat with a quick release, or equipped with a second handle (for small children only) and always manned by an observer/handler. Should the amputee skier go down, the observer can release the rope instantly, preventing injury.

The Ski Seat[24] (Figure 58) and E-Ski[25] illustrated in Figure 59 are viable answers for the high level bilateral amputee and the paraplegic or quadraplegic who wishes to enjoy the thrill of skiing. The sled is custom constructed and has two skis. The E-Ski, a newer device, has only one ski and a cage seat.

Wind Surfing

Wind surfing is a relatively new recreation which combines aspects of sailing, surfing, and hang gliding. Load coordination and balance compounded by the need to grasp, maneuver, and rapidly let go of a cylindrical boom as well as uphaul a rope with mast and sail in tow are some of the obstacles the amputee windsurfer faces. A prototype voluntary closing wind surfing terminal device is illustrated in Figures 60 and 61. Other considerations should include special adjustable harnesses and cable systems for ocean or cold water sailing. Salt accumulation can foul cable function and negate terminal device operation. Wet suits, due to their tight elastic fit, will also interfere with cable function if the cable is worn inside the suit. The harness and cable system must be designed to fit on the outside of the wet suit for unrestricted terminal device operation. Leather on the prosthesis or harness should be avoided, as well as hardware which corrodes. Performance wind surfing is a physically and mentally demanding sport, and the amputee needs to be cautious and prepared to participate safely.

Summary

The varied demands of sports and recreation create a multitude of factors which impact the design, construction, and use of a sports prosthesis.

Physical fitness and conditioning, prosthetic design and materials, harness styles, and terminal devices all have roles in determining whether an amputee can engage in a sports activity successfully and safely.

New improved prosthetic devices and designs will continue to evolve to meet these varying demands. Communication between professionals is important in order to share information on the improvements which are made. Designs for high performance limbs and devices for sports and recreation may well pave the way for improved prosthetic technology as a whole.

An open mind, a fresh outlook, an understanding attitude, as well as the patience and willingness to experiment and develop, will inevitably lead to a brighter future for the disabled in sports and recreation.

Figure 58. The Ski Seat.

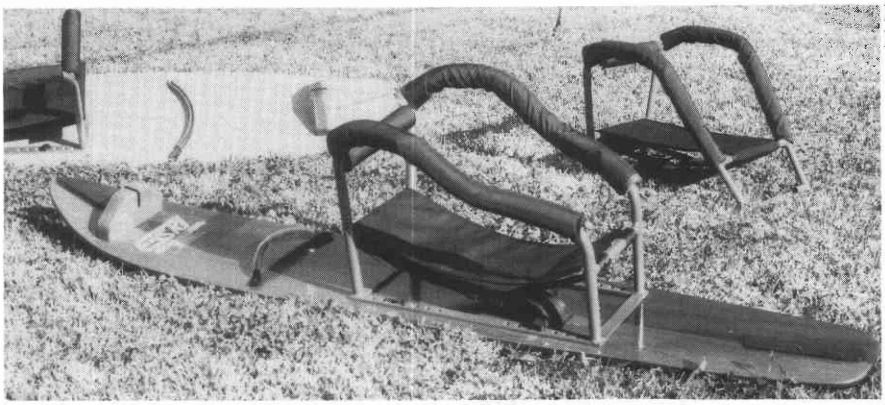
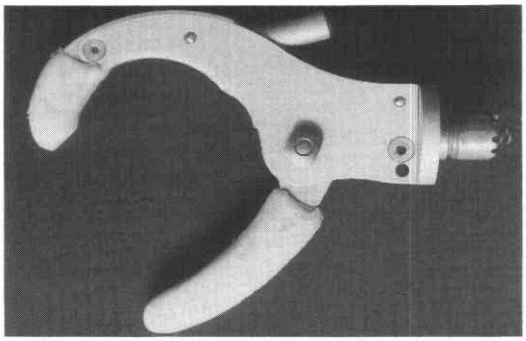


Figure 59. The E-Ski.



Figures 60 (above) and 61 (right). A prototype voluntary closing wind surfing terminal device.

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[14] Courtesy of Bill White, bilateral amputee using two GRIP terminal devices, Waterford, Pennsylvania.

[15] Courtesy of Kent Barber & Bill Dalke, Prototype bicycle aid not commercially available. Inquiries to T.R.S. of Boulder, Colorado.

[16] Courtesy of Bassamatic, Inc. of Canton, Ohio.

[17] Courtesy of Royal Bee Corporation, Pawhuskas, Oklahoma.

[18] Courtesy of Robin-Aids Prosthetics of Vallejo, California.

[19] Courtesy of The War Amputations of Canada, Ottawa, Ontario.

[20] Tradename and product of Innovation Research Corporation, Milwaukie, Oregon.

[21] Courtesy of SR-77 Enterprises, Inc. of Chadron, Nebraska.

[22] Courtesy of R.F. Meyer's photograph of R. Wityczak, a triple amputee.

[23] Courtesy of Carmen Tablada, C.P., Professional Orthopedic Systems of Sacramento, California.

[24] Ski Seat, Mission Bay Aquatic Center of San Diego, California.

[25] E-Ski, Courtesy of E.S.C.I. of Gretna, Louisiana.

[26] Courtesy of the Rehabilitation Centre for Children, Winnipeg, Manitoba, Canada.

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