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In Support of the Hook

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If this were a perfect world, each person would have two perfect, versatile, beautiful hands. Unfortunately, there are individuals who lack one or both of these exquisite devices, whether cogenitally or adventitiously. Thus far, any substitute can only represent a very limited compromise and partial selection of varying fractions among the many desirable functions and cosmetic features needed for a true replacement. There seems no reasonable hope of providing the numerous muscles, nerves, reflexes and voluntary controls needed to position and stabilize mechanical imitations of the multiple joints in the natural hand. Because uncontrolled flexibility, like a loose chain, is merely unstable, the designer is forced to limit the joints severely, providing fixed curves which offer rigidity, yet maximize function.

Fortunately, the customary wrist disconnect mechanisms allow reasonable interchanges to suit specific needs. These changes may not be quite as simple for the amputee as for the normal person who dons warm gloves for cold weather, picks up tongs, tweezers, or pliers to "handle" hot, tiny, or rough objects, or scrubs and manicures in preparation for a party. Nevertheless, the possibility of interchange does allow considerable versatility rather than a forced, even heartbreaking, choice of a single limited terminal device. Each amputee may use an artificial hand with substantial but limited function, and lifelike cosmetic glove when appearance is important, but, then change to a considerably more functional terminal device when appropriate, much like changing evening or business clothes to sports clothes or overalls.[1] In this context of voluntary choice, then, let us consider the appropriate roles for split mechanical hooks.

Note that we can assume that we are far beyond the single hook with sharpened point made notorious by Captain Hook, useful as that was in its time. For the near future, though, we seem limited in practice to a single active control that provides adequate force at any point in a reasonable range of motion and is capable of rapid change, delicate adjustment, and prolonged holding, and preferably offers substantial sensory feedback. The typical Bowden cable (secured to shoulder harness, activated by body motion, and providing some sensory feedback from kinesthetic awareness of human joint position and tactual perception of pressures) provides a substantial degree of function. A source of external power under a single voluntary control, whether valve, switch, or myoelectric signal, may have greater or lesser speed of response, precision of adjustment, and maximum force, but so far it probably supplies less sensory feedback. Occasional adjustments, locking, or presetting of parts can be made by a unilateral amputee with the other hand or by a bilateral amputee through gross motion of the prosthesis to press the terminal device against an object, or squeeze it between the knees, etc.

Thus far, both practical clinical experience and research studies have indicated that additional substantial sources of power, control, and feedback are so limited that they are better used for other functions like elbow flexion, elbow locking, or perhaps wrist rotation instead of for additional motions within a hand or hook. If additional practical sources do become available, of course, they can be used to improve both hand and hook by reshaping either for still greater versatility, or to actuate and release a lock, thereby improving both devices. The hook, though, is intrinsically more versatile than a mechanical hand of equivalent control and sophistication.

It may be useful to recall that the Klingert artificial arm and hand at the end of the Eighteenth Century attempted to control some ten independent motions by cords ending in knobs which the unilateral amputee could move with his good hand along a vest-like garment.[2] Presumably the user soon decided to use the good hand directly for most tasks!

Like many current robots, remotely operated manipulators for nuclear "hot cells" have typically been designed with seven degrees of freedom, including grasp by simultaneous and equal motion of opposing surfaces of the terminal device. Usually a single able-bodied operator has controlled two manual master-slave manipulators, one with each arm, plus assorted leg and body motions to assist in positioning. Even so, we were told some years ago,[3] performance of relatively simple tasks typically took eight to ten times the time needed to do them directly with the bare hands, and early unilateral electrical manipulators took over ten times as long as mechanical master-slaves! At a series of conferences called Project ROSE with participants in the prosthetics research program and others,[4] experts from the nuclear and space programs seemed awed to learn that no bilateral arm amputee (even though substantially limited in independent body motions) needed anywhere near that additional time to perform complex tasks of industry or of daily living. The current interest in applications of robotics to aid quadriplegics may help to revive these interdisciplinary exchanges.

It may be suggested that the performance advantages of the amputee lie not only in motivation, past therapy, and full-time usage, but in basic design philosophy. The classic UCLA studies summarized by Taylor[5,6] and Taylor and Schwarz[7] pointed out the great complexity of the human hand and upper extremity, analyzed the motions and forces used for a variety of activities, suggested reasonable priorities and limitations, and preset or limited position selections in contrast to the equal priority and great range assigned to all motions in many manipulators. The designs of prosthetic hooks typically provide a fixed point of reference for arm placement in the fixed finger. This allows relatively easy and accurate positioning against one side of an object, followed by closing of the hook to surround and grip the object as securely as desired. (The slowly moving thumb or "finger" of the Northwestern University[8] synergetic hand or hook substantially follows this concept, with the rapidly moving member(s) encircling and the high-force thumb then clamping.) In contrast, if both hook fingers (or the thumb opposing the index and middle fingers of a hand) move simultaneously, the user must initially position the arm in relation to an imaginary centerline while mentally allowing for subsequent (perhaps even unequal) motion of the opposing surfaces. This harder task can be learned by long practice and tolerance of frequent error (as we know from sports involving catching objects), but it seems relatively risky for approaching tall unstable objects like laboratory glassware. It also requires good vision, emphasizing the importance of the large safety window in a hot cell and the limitations of periscopes, mirrors, and television systems.

The vast resources of the human hand allow very rapid shaping, grasping, and squeezing to hold objects of assorted sizes, with a reflex adaptation that grips more tightly if slippage starts yet also minimizes the risk of crushing fragile objects. A natural hand spontaneously exerts only modestly more gripping force than needed, whereas the amputee tends to overgrip. With a single control, an artificial terminal device must have a single general shape, though the opposing fingers of the hook may be markedly different. They should encircle and pull in objects within a wide range of sizes rather than extruding them from a V-shaped clamp. At least three contact points are needed for stability; two flat tongs are inadequate or at least require substantial forces to grip rounded objects. The two-position thumb of the APRL hand, preset to normal or wider positions by pressure against some object, is helpful but does not allow the flattening needed to enter pockets.

Attempts have been made to provide unusually large thumb motion. This is to allow the choice of palmar prehension of the finger tips against the thumb or more complete flexion of the fingers into the palm, e.g., the Tomovic Beograd (Belgrade) hand.[9] That kind of versatility requires at least sensor pads and relatively complex logic such as that used by Tomovic or preferably a second hand control. The addition of independent lateral prehension of the thumb, in which the thumb is rotated to press against the partially flexed fingers, is a commonly used human motion, but is limited to small objects and is not considered useful as the primary grip. It might even require dedication of a third control to the terminal device.

In contrast to the severe limitations of an artificial hand with present control sources, a split mechanical hook or other gripping tool may be designed to grasp objects of a wide range of sizes, yet remain sufficiently slim near its closed position to enter pockets to retrieve coins or other objects. Instead of imitating natural form and motion, the hook can be designed solely for function, attaining a sleek though mechanical appearance. In addition, it can be used to push, pull, pry, hammer, touch and hold hot or cold objects, and in general perform many tasks for which even the wonderful human hand requires tools. By ingenious shaping of fingers and choice of axis, the same hook may be used as tweezers for pins, to securely grip many medium-sized objects of daily life, and to surround and lift large objects.

Mass-produced hook fingers (in contrast to earlier hand-forged and slightly variable models) may be economically provided with vulcanized rubber lining for higher friction while retaining a slippery metallic outer surface. (In early field tests with this feature, everyone liked the ability to slip easily into pockets or sleeves. However, one subject, who was long accustomed to starting a sewing machine by pushing the flywheel, complained of the absence of the chemical laboratory tubing used over older hooks. Nothing is perfect!) There may well be a major role for softer external surfaces, especially for children's terminal devices so to prevent injuries. Obviously, the materials should be nontoxic, nonallergenic, noncarcinogenic, and durable.

The APRL and Northrop-Sierra hooks were designed with symmetrical lyre-shaped aluminum fingers held to the case by jam nuts, allowing replacement. Among the many unfinished items on the old research agendas discussed at the frequent conferences and workshops, was the deployment of stainless steel fingers and alternative shapes, including axes canted in relation to a thin sheet gripped by the hook fingers. Occasionally, there was speculation about color in place of the customary polished metal, or of a cosmetic glove designed to fit over a hook.

Greater use of the three-jaw chuck concept, characterized by the index and middle fingers of the APRL hand moving in somewhat inclined planes toward the thumb, is sometimes suggested. However, greater stability must be balanced against greater bulk when closed.

The literature, particularly in patents, discloses a great variety of concepts and shapes of terminal devices. Many were invented by amputees to meet their individual needs, especially in farming or industry. Some designers, notably Steeper in England, emphasized development of many special-purpose tools for daily living as well as for agriculture, industry, and avocations, together with disconnect devices for easy interchange. The demonstrator typically had a fitted case carrying a wide assortment. English colleagues have mentioned that a specific amputee typically received a dress hand, a split mechanical hook, perhaps a single tool appropriate to his particular trade, and (particularly in the case of a bilateral) a long straight split device helpful for grasping toilet paper.

Since 1945, American research programs have emphasized the development of devices to permit any amputee to independently conduct the activities of daily living. Bimanual activities are so varied, due to the size of objects and the gripping force and dexterity required, that vocational guidance for a motivated amputee should include the selection of appropriate vocations which can be carried out with the same device(s) used in daily living. Indeed, most personal tasks are performed on or close to the body, perhaps suggesting wrist flexion devices, whereas vocational tasks normally are conducted on a table or workbench that do not require wrist flexion.

A wide network of clinic teams is available to assist amputees select a prosthesis, return to former occupation, or choose a new vocation. In addition to a reasonably functional hand with cosmetic glove, the unilateral normally receives a versatile hook. The bilateral amputee rarely can function adequately with two artificial hands; sometimes he can use one hand and one hook, if appearance is more crucial than dynamic and independent function. Commonly, the bilateral amputee selects two hooks for routine use.

Fortunately the number of bilateral amputees is very small, yet their needs are particularly great. Paradoxically, to meet their special needs, it has been necessary to first develop devices and techniques which are sufficiently versatile and which are accepted by a majority of the much larger unilateral market (and the professionals who serve amputees). Though present terminal devices are useful and cosmetically acceptable, further research on the specific problems of bilateral amputees is needed.

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