A. Specific Aims

The long-term clinical application of this research is to explore everyday finger posture at rest and during the performance of active and passive functional tasks, especially following therapeutic interventions, in individuals with acquired brain injury. From our clinical and research experience, we have identified a need to collect these data while individuals move around their home and community environments and perform every-day activities such as eating, dressing, and manipulating objects. A primary reason is that actual usage of an affected hand may differ from the functional potential that is traditionally assessed in a clinical setting with ordinal scales such as the Functional Independence Measure or Modified Ashworth Scale. To understand how individuals truly interact with their environments, we plan to obtain quantitative measurements of finger flexion over longer periods of time than traditionally investigated (including during different circadian states including sleep). 24-hour monitoring has proven useful for tracking parameters such as heart rate and blood pressure; however, no practical devices are available to measure finger posture and hand function in a similar manner.

In this specific research, we will complete development and then test a novel measurement device that collects real-time activity data. We address three current problems with existing automated goniometric measurement methods that prevent their use for these types of research.

(1) Individuals with moderate-to-severe reduction in finger range of motion (ROM) have difficulty donning sensor measurement gloves,

(2) regular gloves cause reduced sense of touch at the fingertips and palm, and

(3) no completely wireless wearable measurement systems exist.

We propose to create a novel measurement system by (1) developing a low-cost disposable sensor glove that is applied to the *back* of the hand rather than being donned like a normal glove; and (2) storing data on the glove, or wirelessly transmitting finger flexion data to a remote receiver (data recorder or computer) using new wireless protocols that are very low power and designed for remote sensor monitoring. Data analysis methods will be developed to extract trend and activity data from raw streams of data that describe hand activities objectively; these will be useful for our future studies. The sensor glove will be sufficiently inexpensive so that several can be used at the same time in a large study. These unique elements represent an application of modern technologies to address the shortcomings of existing gloves.

AIM 1: To complete development a low-cost, disposable, wireless sensor data glove that is easy to put on in nearly any hand position. (a) To perform bench testing: evaluating measurement accuracy, resolution, and sensitivity and developing calibration methods. (b) To develop a wireless prototype by adding the wireless link between the glove and remote data recorder/computer.

We will use a new wireless protocol, IEEE global standard 802.15.4/ZigBee™ (a relative of Bluetooth) which requires smaller memory and less expensive hardware, and is optimized for battery-powered monitoring such as home medical monitoring. Furthermore, all data is stored on the glove/forearm unit for home or for short trips in the community. For longer trials, the glove will employ multihop capability using inexpensive repeaters to transmit to a receiver unit in the home (e.g., computer), and will employ data compression and one of several preprocessing methods to extend data collection in the community.

AIM 2: To evaluate the usefulness, repeatability of donning, durability and comfort of the wireless glove in recording continuous finger flexion activity in individuals with acquired brain injury (ABI) (including stroke and traumatic brain injury).

Individuals with a broad range of hand function disability will wear the glove while performing day-to-day activities including the Jebsen Hand Function Test (JHFT), and during extended data collection (>24 hours) in the home and community. A User Assessment of Acceptability will also be performed.

AIM 3: To reduce the continuous data streams of raw finger flexion data to useful outcome variables that a) describe hand activities objectively, and that b) allow evaluating differences in hand function with disability level. Two types of output variables will be developed: Finger Flexion Trend measures to describe trends periodically over time (e.g., in 1-hour intervals), and Hand Activity Template measures to objectively describe individual hand postures that correspond to specific activities (e.g. JHFT).

The device and methods developed here can facilitate a broader understanding of objective functional changes over time or with intervention. The pilot data collected here will be used to pursue funding for two separate research studies; one measuring changes in functional activities (both passive and active) brought about by spasticity interventions and the other exploring the origin of the involuntary flexed finger posture, common after stroke.

B. Background and Significance

Long Term Objectives – Defining the Need

This research focuses on the need for objective measures to understand and treat hand disabilities. The outcome measurement method and device proposed here has the potential to provide data to explore the origins of impairment, and to assist clinicians in their overall patient evaluation, development of reasonable goals, and assessment of treatment efficacy. These projects can improve our understanding of the disability, and the assessment and treatment of the disability.

Proper control of the hand and digits is crucial to manual exploration and manipulation of the environment. Loss of hand function is a major source of disability in neurologic and neuromuscular disorders, frequently preventing effective self-care and limiting employment opportunities. A variety of injuries, syndromes and disease states lead to impairments of hand and finger function, including stroke, traumatic brain injury, spinal cord injury, multiple sclerosis, ataxia, peripheral neuropathy, arthritis and overuse syndromes. Traumatic brain injury (TBI) results in deficits in fine motor skills, speed, and coordination, with severity of the deficit tracking increasing severity of the trauma. Recovery of impairments in hand function do not improve as much as other functional skills such as walking (Kuhtz-Buschbeck et al., 2003). In stroke, finger extension is the motor function most likely to be impaired following stroke (Trombly, 1989), and has a profound impact on disability. One study in the United Kingdom reported that six months after a stroke, more than half of the subjects were dependent on others for help in activities of daily living (Wade, 1994). For TBI, fewer statistics are available on the incidence and objective measure of hand function impairments, although Hiller et al. (1997) report deficits in upper limb activity at 30%. Outcome studies after stroke and TBI (both referred to as acquired brain injury or ABI), have focused primarily on behavioral and cognitive issues or gross functional measures such as changes in the Functional Independence Measure, employability, Disability Rating Scale, Glasgow Outcome Scale or quality of life measures (Hammond et al., 2004; Dikmen et al., 2003). Most deficits are reported in terms of functional limitations rather than specific motor impairments (Katz et al., 1998). Many studies have published motor function results in children with TBI, although most do not isolate upper limb function as a separate variable or measure function using an objective tool (Wallen, 2001).

Exploring the origin of hand impairments: Following traumatic brain injury or stroke, spasticity, tonic activity and excessive muscle coactivation may develop progressively in the hand (Kamper, 2000; Kamper and Rymer, 2001; Kamper et al., 2003). These characteristics are present in the long finger flexor muscles, but not in the long extensors; the source of this asymmetry is unknown. It appears to have a supraspinal origin because this flexion bias in the hand is not typically observed in individuals with complete spinal cord injury. One hypothesis asserts that heightened activity of the flexor motoneurons arises from the brainstem. Stroke survivors have provided anecdotal evidence of diurnal variation in hand posture, beginning with relatively extended fingers in the morning and evolving throughout the day into a fisted posture. If verified, this could suggest a role for the hypothalamus, which is closely associated with circadian rhythms. Interestingly, endocrinal secretions from the hypothalamus may be elevated following stroke (Franceschini et al. 1994; Qu et al. 1995). Unfortunately, it is not currently possible to monitor this hand posture during normal daily activities for a 24-hour period. The development of the device proposed here would provide an important new tool to advance this research.

Evaluating treatment efficacy in terms of objective hand function. Despite the significance of hand impairment following both stroke and TBI, treatment options are limited and largely unproven. An objective measure of hand function would facilitate evaluation of treatment options, although true objective function is rarely obtained. Studies addressing quantitative measurement of hand function have rarely been a focus despite literature that shows that hand function after acquired brain injury can be improved with interventions such at botulinum chemoneurolysis or constraint induced therapy (Page et al. 2003; Brashear et al. 2002; Pavesi et al. 1998; Yablon et al. 1996; Karmen et al. 2003). Although many subjective and objective outcome measures have been proposed, the most common outcome measure for the upper extremity has been the assessment of tone using the Modified Ashworth Scale (MAS) (Munin et al., 2004). Brashear et al. (2002) used the Disability Assessment Scale to subjectively evaluate functional outcome. Although it related to tone assessed by the Ashworth Scale, it did not correlate overall function with hand position or movement. Unfortunately, current assessment methods fail to capture the entirety of the recovery process (Johnk et al., 1999) or the efficacy of an intervention in an objective manner (Brashear et al., 2002; Elovic, Simone and Zafonte, 2004). Precise measurements of various aspects of finger motor control can be made in the laboratory (Darling et al., 1994; Li et al., 2003; Lang and Schieber, 2004) but these data are not always predictive of actual hand use.

Thus, an opportunity exists: a device which could monitor hand activity during the course of a day, at home and in the community, would provide valuable information to evaluate impaired hand function of both passive and volitional activities. Quantitative real-time measurements can document the effects of an intervention (e.g., pharmacologic, therapeutic or chemoneurolytic) by correlating functional abilities with specific task performance (e.g., fine motor control - use of a key or hand in a functionally assistive manner).

The device and method proposed here would help meet these two major needs: to explore the origins of the impairment in hand function, and to plan treatments and to evaluate treatment efficacy in terms of hand function and daily activities.