QUANTIFYING IMPAIRED HAND FUNCTION IN THE CLINICAL ENVIRONMENT

C.M. Light [a,b], P.H. Chappell [b], P.J. Kyberd [c]

[a] Institute of Biomedical Engineering, University of New Brunswick, Fredericton, Canada
[b] Department of Electrical Engineering, University of Southampton, Southampton, UK
[c] Oxford Orthopaedic Engineering Centre, Nuffield Orthopaedic Centre, Oxford, UK

ABSTRACT

The Southampton Hand Assessment Procedure (SHAP) has been developed specifically to enable the broad-based evaluation of hand function irrespective of the disability, thereby allowing assessment of both natural and prosthetic hands [1,2]. This technique enables a contextual result to be formed (relative to normal hand function), hence providing a quantifiable index of functionality rather than the more conventional subjective measures. The establishment of normative data trials and subsequent statistical analysis demonstrates the procedure to be both reliable and repeatable.

The procedure has been undergoing evaluation at hand rehabilitation and prosthetic fitting centres. The subject group consists of those with impaired natural hand function (ranging from traumatic injury to diseased joints), as well as unilateral amputees and those with congenital deficiencies of the upper limb. These initial cases have assisted in the refinement of the index of functionality that results from the procedure.

The perceived hand function of these case studies is presented in comparison with the SHAP results. Quantification of functionality is of clinical importance to allow surgeons and therapists to monitor rehabilitation, and preliminary results suggest that the Southampton Hand Assessment Procedure provides a critical contribution to this process.

INTRODUCTION

Conventional methods of assessing hand function do not address the need for a standardised and objective procedure [1]. Yet, there is a key requirement to quantify the hand's functional capability to allow surgeons and therapists to monitor progress during rehabilitation.

Although there are a significant number of natural hand assessment procedures, the evaluation of hand prosthesis function is limited in scope. Moreover, results obtained from quantifying the effectiveness of these devices are largely obscured by a lack of reference to a benchmark. Consequently any objective evaluation of hand function should be capable of application to both natural and prosthetic hands.

The quantification of hand function during such procedures traditionally has occurred through various methods ranging from time measurement to subjective scoring. Although time is obviously an easy parameter to measure and manipulate statistically, it is not necessarily the most valid appraisal of hand function [3-5]. However without suitable alternatives there are few other objective methods by which to evaluate functionality.

Any hand assessment procedure must ensure that all ranges of grip are included, with direct relevance between prehensile patterns and the selection of activities of daily living. In order to develop a series of tasks based on prehensile patterns, the classifications of grip must be defined (see Figure 1). Although there appears to be little conformity to specific categories of grip description, the general characteristics remain similar. Based on the classifications of Kamakura [6], the following categories were used in the development of a new test, the Southampton Hand Assessment Procedure (SHAP): lateral, power, tripod, tip, extension, and spherical (also termed flexion).
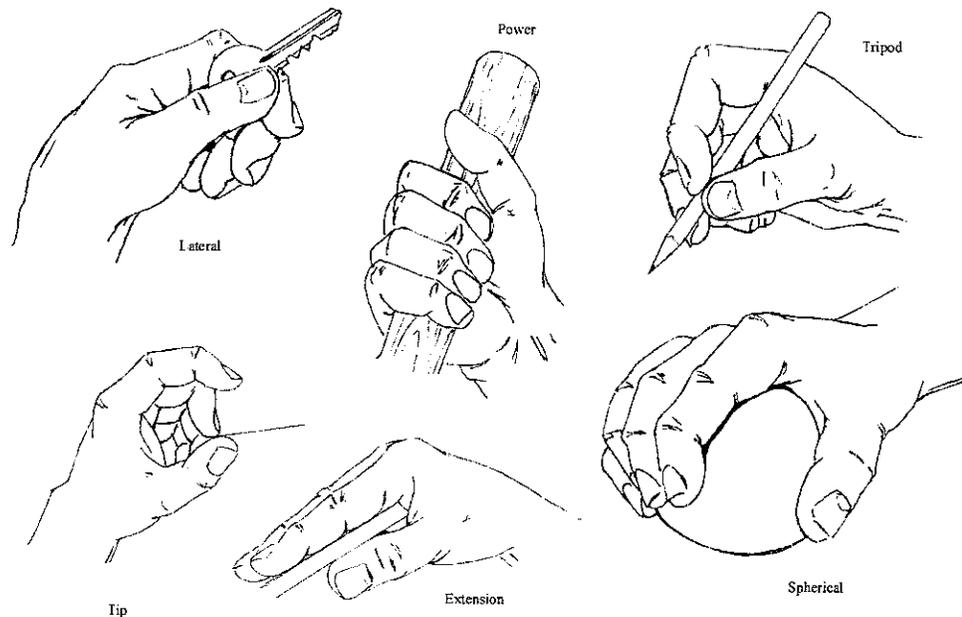
Figure 1 - Classification of Prehensile Patterns

The purpose of prehension classification for hand assessment tasks is to ensure the evaluation of a complete range of grip patterns, thereby providing a balanced assessment of functionality. Despite the differences in determining individual prehensile patterns, the vast majority encompasses the same range of movements regardless of classifications or terminology. Therefore their primary use is the assurance of adequate functional range assessment, rather than the identification of grip patterns during grasping.

SHAP Methodology

The stability of grip or deviation of prehension from a norm has frequently been evaluated by assessor opinion. The Southampton Hand Assessment Procedure [2] has been designed around the timed measurement of standardised tasks. The test requires the subject to perform a series of 12 'abstract' tasks, as well as 14 activities of daily living (ADL). The form board (or abstract) tasks are used to assess prehension without the complication of tools or equipment used during ADL that often cause intermediate grip patterns.

The form board objects are produced in two sets (see Figure 2a); a set of lightweight objects (predominantly balsa wood) for each of the six prehensile patterns, and a similar set constructed from aluminium. This enables assessment of not only the grip form but also compensates for subjects with weak grip pressure (thereby highlighting a difference in performance whilst executing the heavier object tasks).

Sollerman and Sperling [7] estimated the percentage use of their eight types of grip pattern during activities of daily living. The number of SHAP activities of daily living (see Figure 2b) utilising each grip was compiled in approximate proportion to these values to ensure that the assessment of functionality was directly related to the likely everyday use of each grip. This enables the measure of overall functionality to be obtained from a summation of results without the need for any weightings or adjustments of the data.
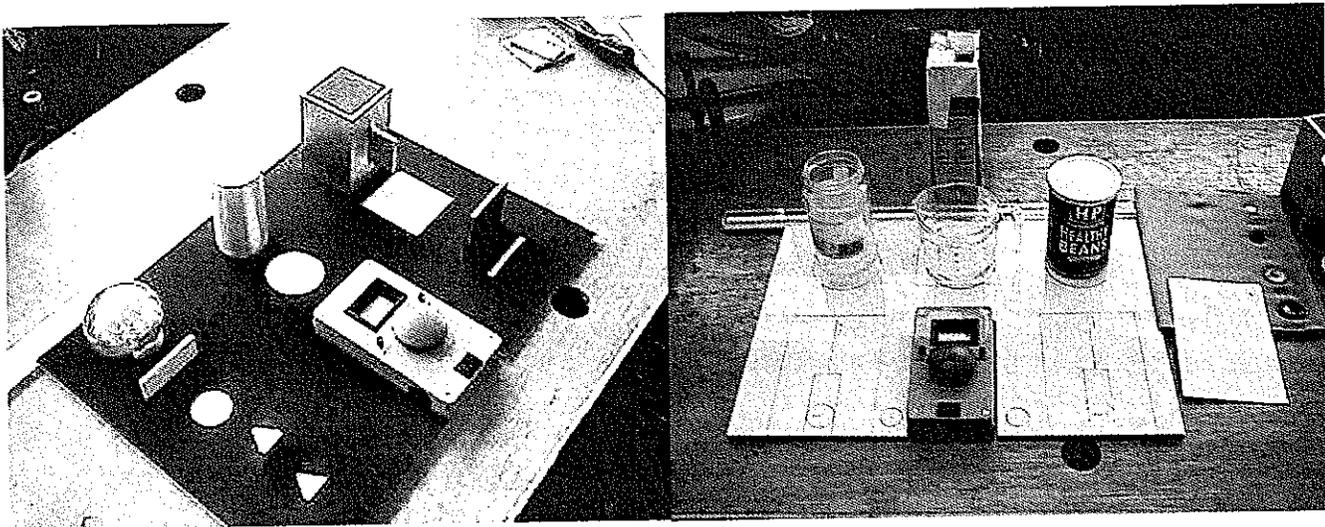
Figure 2 - (a) Abstract Object Form Board (b) Activities of Daily Living

Any activities requiring subjective assessment, or likely to cause a large variability in timing were omitted. For example, the task of writing, although an important everyday activity, was excluded on the basis of large variability in the performance of writing skills with no relevance to hand functionality (i.e. the speed of writing is not necessarily linked to hand dexterity).

Fourteen activities of daily living were selected based on these criteria (see Table 1).

Task Number	Task	Grip Classification	Task Number	Task	Grip Classification
1	Pick-up coins	Tip/Tripod	8	Lift large 'heavy' object	Power
2	Buttons	Tripod	9	Lift large light object	Power
3	Food cutting	Tripod/Power	10	Lift weighted tray	Lateral/Extension
4	Simulated page turning	Tripod/Extension	11	Rotate key 90	Lateral
5	Remove jar lid	Spherical	12	Zip	Lateral/Tip
6	Pour water from jug	Tripod/Lateral	13	Rotate screw 90	Power (with precision)
7	Pour water from carton	Spherical (flexion)	14	Rotate door handle	Power

Table 1 - Selected Activities of Daily Living

Normative data trials assessed nine males and nine females, with each evaluation replicated three times by the same assessor. Interrater trials were also carried out to ensure repeatability (and inherent standardisation) of SHAP. A combined normative database of 24 subjects, each with three replicate assessments, was subsequently used to provide the mean task times and standard deviations from which to evaluate the clinical subjects.

The variability of these times was found to be in increasing proportion to the mean time to complete the task. Hence any attempt to utilise the total task time or a mean overall time will cause an unbalanced result; for example if two tasks take 1 sec and 10 sec to complete respectively, then an arithmetic mean of these scores would be weighted much more heavily by the test taking 10secs. In order to reduce this weighting effect (which is likely to be more noticeable in pathological hand function), then the logarithm of each task time is taken. Thus the normative database consists of 26 individual task times

$$\mu_{total\,task} = \log_{10}\left(\frac{1}{n}\sum_{n=1}^{24} t_{total\,task}\right) \qquad \text{Equation 1}$$

(μ_{task}), total time (μ_{total}), and standard deviations obtained from the times (t) of 24 normal subjects (n) according to Equation 1.

CLINICAL DATA ANALYSIS

At the time of writing, the hand assessment procedure has been used to assess 18 patients with varying hand trauma or disability, and one prosthesis user fitted with an Otto Bock myoelectric hand and wrist. The functionality of these patients has been quantified relative to 'normal' times by the use of z-scores and a relative scale. The z-score quantifies a patient's result in terms of standard deviations from the norm according to Equation 2

$$z_{t,i} = \frac{x_{t,i} - \mu_{t,i}}{\sigma_{t,i}} \qquad \text{Equation 2}$$

where

$$FS_{t,i} = 100 - (z_{t,i} \times FI) \qquad \text{Equation 3}$$

z = z-score

t = total

i = 1,2, 6, representing the six prehensile patterns

x = subject time

μ = normative mean time (from Equation 1)

σ = normative standard deviation

FS = Functional Score

FI = Functional Index

This enables a measure of 'deviation' from the norm for each patient. A z-score is obtained for the overall assessment time (z_t), for each of the prehensile patterns (z_i), and if necessary, for each task. The total time z-score reduces a multidimensional problem from 26 variables to one, and therefore must be considered as an approximate quantification of function rather than an accurate representation. Hence, the assessor is provided with an overall approximation of function (from z_t), and then may subsequently choose to study the prehensile patterns (z_i) to highlight specific areas of functional difficulty (whilst the analysis of individual tasks is warranted only for the study of specific anomalies in test results).

In the case of a subject taking an excessive period of time to complete, or unable to accomplish the task, then a boundary must be introduced. Other assessment procedures [3, 8] have imposed boundary times and conditions without consideration of the individual nature of the task. For example Jebsen [3] limited subjects to 80 secs for all tasks that ranged from 'writing' (with a normal mean time of 12 secs) to the 'moving of large light objects' (with a normal mean time of 3 secs). However a more accurate estimate of the limit is obviously the time beyond which one can assume minimal function. Given consideration of previous functional assessments, as well as an analysis of existing clinical data, a boundary factor of 20 times that of the norm was imposed. Subjects were allowed to perform the task, but their times were subsequently limited if necessary.

Having imposed such a boundary condition, the z-score measure can then be converted to a sliding scale in a similar method to that of IQ ratings. The normative mean time is centred about a score of 100 on a new functional rating scale, according to the formula in Equation 3.

The functional index is used to equate a unit of 'functional score' to the number of standard deviations from the norm. This figure is determined based on the assumption that time in excess of 20 times the norm results in zero function. By multiplying the normative times by this limit, and using Equation 2 as before, the z-score obtained is approximately 23 (i.e. a subject performing each task at the boundary condition will be twenty three standard deviations from the norm). Given the functional rating range of zero (for non-functional) to one hundred (for normal function), then each standard deviation from the norm equates to $^{100}/_{23}$ rating points, which is represented in Equation 3 as the Functional Index. The current index value has been rounded to 5, however further clinical trials are expected to contribute to the refinement of this value. Although of no impact to the relative functional rating of each subject, the index ensures that all subjects remain above the realistic function boundary of a zero score.

Example results are given below for a section of the clinical trial group (Table 2). As can be seen from the data, although an overall functional score may indicate a level of dysfunction, the specific prehensile patterns may hold more information as to the true difficulties that the subject encounters. For example, subject E (suffering from a fractured wrist) encounters little relative difficulty in performing fine precision tasks such as tip and tripod grips, yet has notable adversity in carrying out lateral grip tasks. This is potentially due to the pronation/supination of the forearm usually associated with these tasks that also effect wrist movement.

The data also highlights specific difficulty for the prosthesis user, who as expected has minimal functionality compared to the rest of the group. This subject has severe impairment in the performance of power grip tasks, which is likely to be attributable to the limitations of the single degree of prosthesis.

Subject	Dysfunction	Overall Functional Score	Prehensile Group Functional Score					
			Spherical	Tripod	Power	Lateral	Tip	Extension
A	Flexor tendon injury (middle and little finger)	82.34	82.35	81.89	84.33	84.47	80.22	83.66
B	Dypytrens Disease Release	83.14	80.32	84.68	79.67	81.73	87.72	87.50
C	Proximal IP joint arthrodesis (little finger)	82.56	84.54	82.77	79.48	76.71	82.80	85.89
D	Flexor tendon injury (middle and little finger)	77.89	77.06	80.08	81.24	76.08	80.81	80.55
E	Fractured wrist	78.5	83.59	82.42	72.73	66.61	90.33	84.74
F	Amputation (index, middle and ring)	64.78	68.33	64.56	65.78	53.03	70.98	72.00
G	Below Elbow Prosthesis User	32.61	33.41	22.97	21.50	25.21	32.98	42.16

Table 2 - Functional Ratings of Clinical Data Sample

CONCLUSION

There are a significant number of natural hand assessment procedures in existence, however few address

the requirements of objectivity and standardisation. These factors are necessary to provide a reliable quantification of hand function for use as a clinical outcome measure. Conversely the measurement of hand prosthesis function has tended to centre on engineering assessments that fail to provide any reference or benchmark for the results obtained. Consequently the Southampton Hand Assessment Procedure has been developed to address the broad-based requirements of evaluating hand function, whether natural or prosthetic. The procedure aims to cover a full range of prehensile patterns by the use of both abstract objects (designed to encourage specific grip forms), and activities of daily living, totally 26 individual tasks.

Normative data trials were carried out to enable the subsequent evaluation of impaired hand function with respect to a benchmark standard. A mean total time to perform all tasks, and mean times for each of the 26 tasks, was calculated along with associated standard deviations. Each task has an associated prehensile pattern classification (lateral, power, tripod, tip, extension or spherical), and these times were summed to form a result for each prehensile group.

The results of the impaired function subject group was then quantified with respect to this normative database. A z-score is obtained for the overall assessment time, and for each of the 6 prehensile patterns, which rates the subject's performance by standard deviations from the norm. This is then converted to an arbitrary functional rating scale, centred about a normal result of 100.

The ability to provide an overall measure of hand function is important, but perhaps secondary to the ability to identify specific areas of functional difficulty, as produced by the prehensile pattern group results. The procedure is not aimed at quantifying the quality of life of the subject, nor indeed the subject's overall functional ability. Instead the emphasis lies in evaluating the performance of the hand, whether natural or artificial, so that rehabilitation, treatment, or the focus of additional research (in the case of prostheses) may be better evaluated and directed. The continued clinical trials of this procedure are hoped to aid in the refinement of the statistical evaluation whilst simultaneously providing valuable information to therapists and researchers alike.

ACKNOWLEDGEMENTS

REFERENCES

1. Light, C.M., Chappell, P.H, Kyberd, P.J., Ellis, B.S., "A Critical Review of Functionality Assessment in Natural and Prosthetic Hands", British Journal of Occupational Therapy, 62(1), 7-12, 1999

2. Light, C.M., Chappell, P.H., Kyberd, P.J., "The Southampton Hand Assessment Procedure", 5th Triannual Conf. of the British Association of Hand Therapists, Oxford, 28-29th September 1998

3. Jebsen, R.H et al., "An objective and standardised test of hand function", Archive of Physical Medicine and Rehabilitation, 50(6), 311-319, 1969

4. Moberg, E., "Criticism and study of methods for examining sensibility in the hand", Neurology, 12, 8-19, 1962

5. Edelstein, J.E., Berger, N., "Performance comparison among children fitted with myo and body-powered hands", Archive of Physical Medicine and Rehabilitation, 74, 376-380, 1993

6. Kamakura, N et al., "Patterns of static prehension in normal hands", American Journal of Occupational Therapy, 34(7), 437-445, 1980

7. Sollerman, C., Sperling, L., "Evaluation of activities of daily living - especially hand function" Scandinavian Journal of Rehabilitation Medicine, 6, 139-143, 1978

8. Sollerman, C, Ejeskar, A., "Sollerman hand function test - a standardised method and its use in tetraplegic patients" Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery, 29(2), 167-176, 1995