# Muscle Force Assessment in the Presence of Indeterminate Deficiency

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Keywords: Indeterminate Deficiency, Force Assessment, Mind Distraction, Computer Adaptive Testing.

Abstract: Indeterminate deficiency is encountered when a subject puts an artificial limit on his/her muscle abilities, in which case his/her true muscle force cannot be assessed in a straight forward manner. Self-restriction of muscle performance during testing may be unintentional due to lack of motivation, lack of self-confidence or due to fear of pain. It can, however, be intentional resulting from unwillingness to cooperate. The aim of this study was to develop an objective system aimed at directing subjects into generating more intense muscle forces than they aimed, thus leading to their true force potential. The methodology used combines mind distraction techniques and Computer Adaptive Testing (CAT) theory. The first element is aimed at distracting the examinees from restricting their muscle force, or shifting the interval of convenience of their performance. The examined subject is thus directed into generating higher muscle forces than he/she has intended to, thus reaching the highest possible force. Practically, the tested subject is asked to perform tasks of varying intensities, visually presented in subject-unanticipated real-time converted-scale display biofeedback. For the second element of our methodology we made use of the Item Response Theory custom-tailored itemized test, for people with various ability levels. A developed iterative CAT algorithm provided, individually for each subject, rapid convergence to the highest force level possible. The results of this study bear potential significance in two major areas: Rehabilitation Medicine, by indicating training procedures for unconfident patients and in Occupational Medicine, for the functional evaluation of subjects who exhibit lack of motivation or cooperation.



## 1 INTRODUCTION

The neuro musculo skeletal system is characterized by redundancies, whereby a motor task can be normally performed with the simultaneous involvement of more muscles than strictly necessary. Furthermore, this same task may be performed in multiple ways, with different muscle combinations. From the mechanical viewpoint the musculoskeletal system is indeterminate, whereby the number of unknown muscle forces exceeds the number of available equations. Impairment has been associated with reduced redundancy (Mizrahi et al 2011). The level of indeterminacy was shown to decrease with the reduction of redundancy, e.g. through single stance (compared to double stance) standing or through fatiguing of part of the muscles implying, that higher levels in the nervous system become more unequivocally related to lower levels (Levin et al 2000; Suponitsky et al 2008;). An interesting type of deficiency is found when neither the identity of impairment, nor its extent are certain, thus suggesting the term Indeterminate Impairment.

This study deals with false impairment, encountered when tested subjects, either unintentionally or intentionally, exert an untrue limit on their force, in which case their real capacity cannot be disclosed in a straight forward measurement. The need for force measurement arises when physical performance is to be assessed such as in Occupational Medicine.

Assessment of muscle force is usually performed by evaluating the maximal voluntary contraction (MVC) of the tested muscle (Chaffin et al, 1999), necessitating cooperation of the tested subjects. However, since the muscles are sub-activated because the tested subject does not apply his/her maximal force capacity, the accuracy by which the measured force reflects the real muscle capacity becomes questionable (Shechtman et al 2012, Garcia et al 2014). This may happen in either of the following two cases: (a) unintentional self-restriction, due to lack motivation or self-confidence, fear of pain or injury



Mizrahi, J., Marcus, E. and Wiener, A.
Muscle Force Assessment in the Presence of Indeterminate Deficiency.
DOI: 10.5220/0007565400810086
In *Proceedings of the 12th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2019)*, pages 81-86
ISBN: 978-989-758-353-7

(Sullivan et al. 2009), guarding; or (b) deliberate restriction, due to low, or no willingness to cooperate.

Muscle force malingering has been reported in the literature. Although there are no definite indications about the extent of malingering during physical functional assessment, reviewed studies have indicated that malingering does occur within the chronic pain setting, at the rate of 1.25-10.4% of chronic pain complaints (Fishbain et al 1999).

Here, we developed a Computer Adaptive Testing (CAT) system (Hambleton 2000; Hays et al. 2000), specially adapted for physical testing, and aimed at objectively evaluating muscle forces, in those cases where the muscles are sub-activated. Basically, CAT is based on modern testing theory to select the optimal next task to be administered based on the examinee's previous responses.

In addition, we established a computerized task algorithm, combined with real-time visual feed-back designed to distract the examinees' attention away from the actual testing objectives. We hypothesized that, by combining CAT principles and mind-distraction techniques, it is possible to direct subjects into generating a greater sub-maximal force than they intended (Sullivan et al. 2009; Wiener et al 2007). In this way, it was expected that a more objective MVC can achieved from the tested subject (closer to the real capacity of the muscle), which is less dependent on the level of cooperation of the participating subjects in the testing procedure. The results of this study bear potential significance in two major areas: Rehabilitation Medicine, by indicating training procedures for unconfident patients and, in Occupational Medicine, for the functional evaluation of subjects who exhibit lack of motivation or cooperation.

# 2 MATERIALS AND METHODS

## 2.1 Apparatus

Muscle forces were measured through the corresponding joint torques. Two experimental systems were thus designed to measure the torques during isometric extension efforts of the knee, or during isometric flexion of the elbow. The systems were adjustable with restraints on which the volunteer subjects were seated during testing (Fig. 1). Data acquisition was made by sampling the force from the transducer at 200 Hz into an A/D acquisition card and a Lab-View interface (National Instruments Corporation, Austin, TX).

## 2.2 Procedure

The concept of CAT combined with mind distraction was tested on a group of 11 able-bodied female subjects, aged 26.2 (1.6) years, who were instructed to cooperate in fulfilling the testing instructions, as described in Table 1.

First, the examinee was asked to exert the highest isometric force, denoted as the initial maximal voluntary contraction (MVCi). This was repeated three times with an interval time of 10 min for averaging the actual MVCi. It was assumed that, since the subjects were cooperative, the measured MVCi was representative of the true initial maximal voluntary contraction. Thus, except for adjustment due to possible existence of fatigue, the individual MVCi could be used as a reliable measure for force normalization.

Table 1: Summary of the Testing protocol, indicating subject cooperativity.

| | |
|---|---|
| Exert MVC | Subject cooperates |
| Training to memorize Fssl | Subject cooperates |
| CAT tests | Subject does not obey task, but instead observes his/her force limit Fssl |
| Post-test MVC | Subject cooperates |
| Repeatability of Fssl | Subject cooperates |

Thereafter, each tested subject was trained to set and memorize a self-selected force limit Fssl (usually near 20–50% his/her MVCi). The training process was made with real-scale feedback, as displayed on a monitor and was not limited in time. Training was terminated when the examinee felt confident in being able to memorize his/her Fssl, which usually corresponded to force reproducibility of better than 5% of the selected Fssl. This memorized force (force or joint memory) was later used by each subject to apply force restriction irrespective of the force being instructed to apply in the testing algorithm. It should be noted that successfully memorizing this limit force and observing the limit was essential for indicating whether the testing algorithm was capable of distracting the tested subject to higher forces.

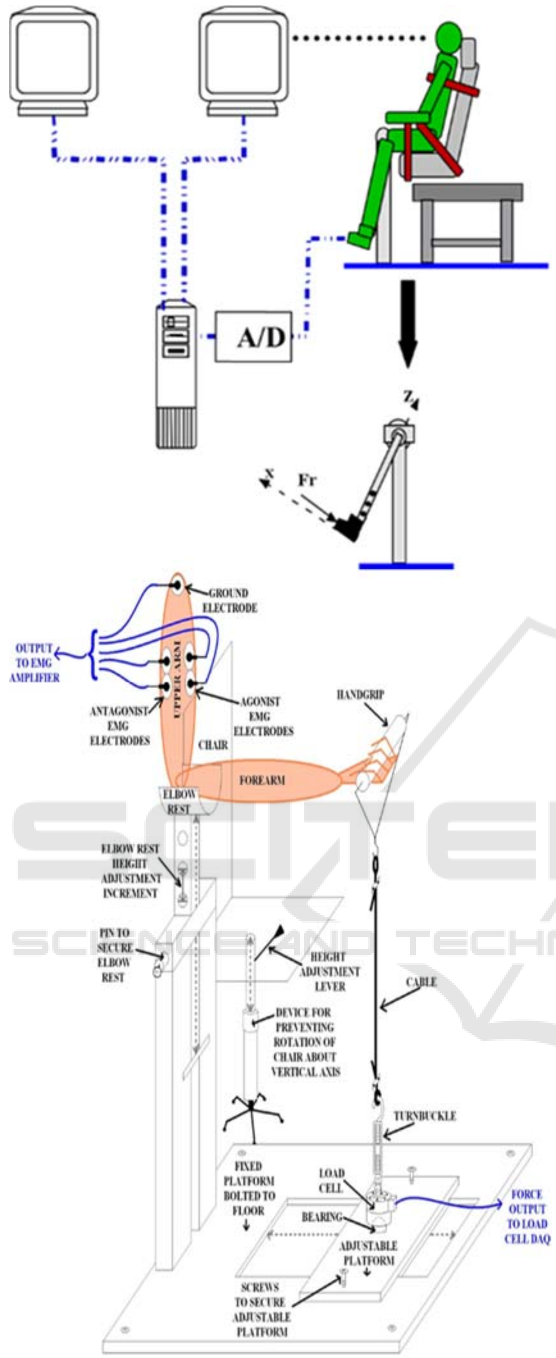


Figure 1: Isometric testing apparatus: top, for knee extensors; bottom for elbow flexors. Experimental features include, among others, dual visual screens and EMG electrodes.

## 2.3 CAT Testing Algorithm

The CAT phase consisted of two different tests: The algorithm-test and, the repeatability-test. The algorithm-test was designed to verify whether the CAT system could cause the examinee to unintentionally exert a higher force than he/she intended to. We developed an algorithm aimed to distract the examinee's attention from the objective of keeping steady the memorized limit force on each new task. For this purpose, the algorithm consisted of two scales to describe the examinee's effort. A real scale was displayed on the operator screen monitor and a false (converted) scale was displayed on the examinee's (apparent) screen monitor (Fig. 1, top).

The examinee was asked to perform a force-application task which, on the operator monitor was displayed in MVC percentage units (real force). This was indicated on the screen by means of two horizontal parallel "target lines" between which the force should be aimed. On the examinee's monitor, this same task (apparent force) was represented in a converted scale. The scaling (or distraction) factor SF is defined as Apparent Force / Real Force. During task performance, the examinee was reminded not to exceed his/her self-selected limit force (Fssl).

For each testing cycle, a baseline mission was set and, every task was considered to be equal 100%, 50% or 150% of this baseline according to the difficulty level set by the force target factor (FTF).

On the operator screen, the real Ftarget force was displayed. On the examinee's screen the task was represented as the product of the target force, the scaling factor (SF, or distraction factor) and the force target factor (FTF). Values of SF, and FTF in a cycle are given in Table 2.



Table 2: Values of SF and FTF for every task, in a one complete cycle.

| | One Task cycle | | | | | |
|---|---|---|---|---|---|---|
| Task | 1 | 2 | 3 | 4 | 5 | 6 |
| SF | 1 | 2 | 1 | 0.5 | 0.5 | 0.5 |
| FTF | 1 | 0.5 | 0.5 | 0.5 | 1 | 1.5 |

The operator terminated the algorithm test when the examinee exerted a significantly higher force than his/her self-selected limit force, or after completion of two cycles.

## 2.4 Adjustment for Muscle Fatigue

After completion of the CAT, the maximal voluntary contraction was measured again to verify whether the muscle had undergone fatigue during the test (final, MVCf). This was repeated three times and the average was taken to represent the actual MVCf. Thus, the true final maximal voluntary contraction MVCf, provided a correction for MVCi due to the possible development of muscle fatigue during the test. The values of MVCf and MVCi were used to linearly interpolate MVCtask, corresponding to each actual task and to which the force values were normalized during the test.

### 2.5 Repeatability of Joint Memory

Repeatability of joint memory was tested one week after the CAT with similar number of cycles and testing durations as in the CAT. Its purpose was to confirm the subject's ability to remember her Fssl.

## 3 RESULTS

A typical force-task during a complete test cycle is shown in Fig. 2. The memorized force limit (0.4 MVC, in this case) is displayed by the horizontal line. It is noted that the task intensities generated by the CAT algorithm demonstrate a zigzag pattern. The tested subject obtains these tasks on his/her screen in a false (converted) scale, thus distracting him/her from the real task, resulting in producing higher forces than he/she meant to.

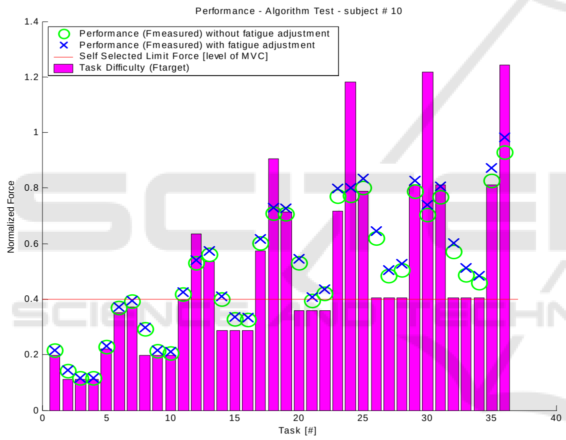


Figure 2: Force tasks in complete cycle (36 tests) for subject 10 (with Fssl at 0.4 MVC, shown as a horizontal line). Note the zigzag effect of the algorithm on the task intensity between the tasks. This effect is added to the distraction effect caused on the subject's screen. Force results are shown: without fatigue adjustment (o) and with fatigue adjustment (x).

Fig. 3 demonstrates the force output for one subject, as obtained using the CAT in a complete cycle (top), as compared to the force output during the repeatability test. The force values at the initial and final ends of the test were normalized by using the respective MVC values. For any intermediate task, the MVC was interpolated. In the CAT (upper panel) the examinee's performance was characterized by oscillations of the exerted forces below and over Fssl. The applied force eventually reached a magnitude of as high as 2.34 Fssl (score of the CAT). However, in the repeatability test (lower panel), the fluctuations around the level of Fssl were smaller compared to the CAT with a maximum score of 1.88 Fssl. Thus, the testing algorithm was successful in 'tricking' subject 5 and a higher force was obtained despite her attempts to maintain the memorized force Fssl.

Summary of the scores, for the CAT and for the repeatability tests, for all the subjects, is presented in Table 3. The mean score values of the CAT and the repeatability tests for all the participants were 1.995 Fssl and 1.554 Fssl, respectively, with a statistically significant difference ($p < 0.05$) between them. Ten out of the eleven subjects rendered a higher force than intended by their self-imposed limit.

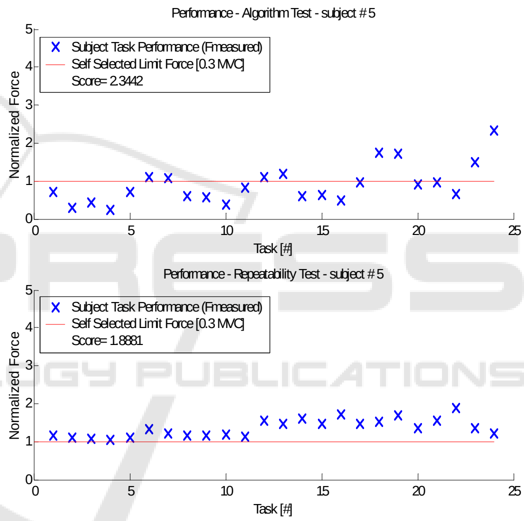


Figure 3: Force applied (normalized to base-line force Fbl): comparison between CAT and repeatability tests (subject 5). The value of Fssl was in this case 0.3 MVCi. Test score denotes the highest force value attained during the test (CAT, or repeatability).

## 4 DISCUSSION

Accurate functional testing and physical measurement is important for the objective diagnosis of physical impairment. This however is being prevented whenever the tested subject sets an artificial upper limit on his/her muscle force, resulting in sub-activation of the muscle. The true force capacity cannot in this case be assessed or utilized in a straight forward manner. In this study a model of able-bodied subjects served to simulate muscle sub-

Table 3: Results of algorithm and repeatability tests for all subjects.

| Subject # | CAT Algorithm | Repeatability |
|---|---|---|
| 1 | 1.979 | 1.403 |
| 2 | 2.089 | 1.183 |
| 3 | 2.436 | 2.674 |
| 4 | 0.957 | 0.954 |
| 5 | 2.344 | 1.888 |
| 6 | 1.385 | 1.155 |
| 7 | 2.027 | 1.552 |
| 8 | 3.193 | 1.742 |
| 9 | 1.850 | 1.590 |
| 10 | 2.458 | 1.672 |
| 11 | 1.225 | 1.279 |
| Average (SD) | 1.995 (0.64) | 1.554 (0.47) |

activation. These subjects were trained to memorize a certain sub-maximal force in their muscle (via its corresponding joint). In subsequent force tasks, each subject was instructed to watch that during task performance his/her memorized force is not exceeded. The force tasks were within a series of tests combining CAT and mind distraction. The former element was based on IRT (item response theory), a custom-tailored itemized test based on probability of a favourable outcome for people of various ability levels, and testing was done in iterative steps taking into account the subjects abilities and task scores. The second element, mind distraction, was designed to distracting the examinee from restricting his/her muscle force, or shifting the interval of convenience of his/her performance, so as to direct him/her into generating higher muscle forces than he/she has intended to, and thus reaching the highest forces possible for this subject. The results demonstrated that in 10 of the 11 tested subjects the algorithm was successful in revealing higher forces in knee extensors than intended by the tested subjects. The tests should be extended to elbow flexors as well. These results can serve as an encouragement to apply the method described to populations of subjects characterized by muscle sub-activation, either from unintentional or intentional reasons.

Unintentional muscle sub-activation may be due to lack of motivation, lack of self-confidence, or fear of pain, such as may take place after trauma, injury or surgery and involving time periods of recovery and rehabilitation. Intentional sub-activation is encountered when the tested subject declines to revealing his/her muscle force potential within his/her overall physical functioning and resulting in lack of willingness to cooperate.

The significance of revealing the true muscle force potential is thus clear: In rehabilitation medicine, Increased rehabilitation and treatment progress and efficiency, design and assessment of suitable treatment plan and increased self-esteem of the patient, decreased burden on patients; In occupational medicine, better functional assessment and return to employment, decreased cost to patients, treatment facilities, and insurance companies. Future work should extend the suggested method to these populations.

## REFERENCES


Chaffin, D.B.; Andersson, G.B.J. and Martin, B.J. (1999) Occupational biomechanics. 3rd ed. New York: John Wiley & Sons, pp. 91–130.

Fishbain, D. A., Cutler, R.; Rosomoff, H. L. and Rosomoff, R. S. (1999). Chronic Pain Disability Exaggeration/Malingering and Submaximal Effort Research, Review, *The Clinical Journal of Pain* 15(4): 244-274.

García, D.V., Dierckx, R. A., Otte, A. and Holstege, Gert 2014. Whiplash, real or not Real? A review and new concept. In: *PET and SPECT in Neurology*. Springer, Berlin Heidelberg, pp 947-963.

Hambleton, R. K. (2000). Emergence of item response modeling in instrument development and data analysis. *Med Care* 38:II: 60-65.

Hays, R. D., Morales, L. S. and Reise, S. P. (2000). Item response theory and health outcomes measurement in the 21st century. *Med Care* 38:II: 28-42.

Levin, O.; Mizrahi, J.; Adam, D., Verbitsky, O. and Isakov, E. (2000). On the Correlation Between Force Plate Data and EMG in Various Standing Conditions, In: *Proceedings of the Fifth Annual Conference of the International Functional Electrical Stimulation Society*, T. Sinkjaer, D. Popovic & J.J. Struijk (Eds), pp. 47–50, Center for Sensory- Motor Interaction, Aalborg University, Denmark,. June 18–24, 2000.

Mizrahi, J. (2011). The Role of Electromyograms in Resolving Musculoskeletal Interactions in Able-bodied and Disabled Human Individuals, In: *Advances in Applied Electromyography*, Ed. Joseph Mizrahi, InTech, (ISBN 978-953-307-382-8), pp 3-24.

Shechtman, O.; Sindhu, B.S. and Davenport, P.W (2012). Using the "Visual Target Grip Test" to Identify Sincerity of Effort during Grip Strength Testing, *Journal of Hand Therapy* 25(3): 320-329.

Sullivan, M., Tanzer, M., Stanish, W., Fallaha, M., Keefe, F. J., Simmonds, M. and Dunbar, M. (2009). Psychological determinants of problematic outcomes following Total Knee Arthroplasty. *Pain* 143:123-129.

Suponitsky, Y., Verbitsky, O., Peled, E., and Mizrahi J. (2008). Effect of Selective Fatiguing of the Shank Muscles on Single-Leg-Standing Sway, *J. Electromyography and Kinesiology*, 18:682-689.

Wiener, A., Marcus, E., and Mizrahi, J. (2007). Objective measurement of knee extension force based on computer adaptive testing, *J. Electromyography and Kinesiology*, 17:41-48.