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Quantification of the effects of instruction type, verbal encouragement, and visual feedback on static and peak handgrip strength

Myung-Chul Jung, M. Susan Hallbeck*

Industrial and Management Systems Ergonomics and Safety Research Engineering, University of Nebraska, 175 Nebraska Hall, Lincoln, NE 68588-0518, USA

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Abstract

The purpose of the study was to quantify the magnitude of the influence of the effects of instruction type, verbal encouragement, and visual feedback on static strength and to verify the applicability of the Caldwell Regimen to grip strength measurement. Twenty-one male students participated in the study that employed an isokinetic wrist dynamometer to measure handgrip strength. The results revealed that these three factors had significant positive effects on static grip strength, peak grip strength and time to reach the maximal strength. The findings showed that when subjects were free to perform the handgrip any way they chose (free instruction (FI)), they most closely followed a fast contraction and maintained force (FCM). The strength results from the Caldwell Regimen were also similar to the FCM, but the variability during the exertion was higher with the Caldwell Regimen instructions of a slow contraction and maintain (SCM) than FCM. A modified Caldwell Regimen with a shorter maintained time rather than a long maintained time might allow a more stable "static" strength. In addition, the use of verbal encouragement and visual feedback should be noted, if employed in a strength test.

Relevance to industry

Handgrip strength is commonly used in industrial tasks. The maximum handgrip strength is often measured employing the Caldwell Regimen. This paper examines the static and peak handgrip strengths associated with the subject's preferred handgrip method other instruction types. It also examines the effect of visual feedback and verbal encouragement that are not often associated with industrial work, but are frequently used in strength testing.

Keywords: Caldwell Regimen; Instruction type; Verbal encouragement; Visual feedback; Static grip strength; Peak grip strength

*Corresponding author. Tel.: +1-402-472-2394; fax: +1-402-472-1384.
E-mail address: hallbeck@unl.edu (M.S. Hallbeck).

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1. Introduction

Static strength or maximum voluntary contraction (MVC) has been a basic measure in many ergonomic experiments; therefore, it has been studied for several decades. Static strength has been defined as the maximal force voluntarily and isometrically exerted by muscles (Caldwell et al., 1974; Chaffin, 1975; Kroemer, 1970).

The measurement of static strength seems to be simple; however, it can be affected by a number of internal and external factors. Internal factors are related to physical characteristics and motivation of subjects and external factors involve experimental environments such as instructions given, noise, competition, etc. (Kroemer and Marras, 1980).

Ergonomic protocols, such as the Caldwell Regimen (Caldwell et al., 1974), have been suggested and accepted in order to reduce the variation of the measurement techniques employed. The main instruction set within the Caldwell Regimen is a slow build-up to maximal force in about 1 s and to maintenance of that force for another 4 s. The "static" strength is calculated using the mean score over the first three maintained seconds and strength variations during this period should be within $\pm 10\%$ of the mean. In addition, other factors that can stimulate motivation should be avoided (Caldwell et al., 1974).

However, Chaffin (1975) mentioned that pilot tests were necessary to determine proper times for acquiring a steady state for maximal strength, due to the relationship between muscle groups or articulations involving the strength measurement. Since hands have many articulations and small muscle groups, it is debatable whether only one protocol, the Caldwell regimen, is appropriate for the measurement of static handgrip strength. The capability of the subject to stay within the prescribed $\pm 10\%$ bandwidth about the mean may also be affected by the small number of muscle groups and size of the muscles.

While measuring the static strength, moreover, one of the more common mistakes is to expose subjects to influential factors such as verbal encouragement, instant visual feedback of the strength results, or differing instructions during the same test, even though the effects of these factors have been already proven to influence the motivation of subjects (Berg et al., 1988; Williamson and Rice, 1992). The effects of the visual feedback and motivation on the static grip strength magnitude are not known. In addition, verbal encouragement and visual feedback may affect the static nature of the exertion and encourage a different number of $\pm 10\%$ bandwidth violations during the testing.

Since most industrial applications provide neither visual feedback nor verbal encouragement, these effects must be documented and discussed if they exist. The real-life workplace also does not follow the Caldwell regimen, therefore, the no or free instruction (FI) needs to be compared to the other instruction types to determine which instruction set, if any, it resembles for the dependent variables. This is necessary since most guidelines or limits for exertion are based upon data collected using the Caldwell regimen.

For these reasons, this study quantifies the effects of instruction type, verbal encouragement and visual feedback on static handgrip strength. It also verifies the applicability of the Caldwell Regimen to static handgrip strength by examining the bandwidth (number of outliers) over the maintained time and the effects of instruction type versus a no instruction (free instruction) exertion.

2. Method

2.1. Subjects

Twenty-one male students voluntarily participated in the 1-h study and each used the dominant hand for the grip strength test. Only one subject was left-handed. Averages of age, height, and weight were 26.05 ± 4.19 years, 176 ± 7.42 cm, and 75.81 ± 12.16 kg, respectively.

2.2. Apparatus

As shown in Fig. 1, an isokinetic wrist dynamometer developed by Wilhelm (1997) was used to measure static grip strength. The grip handle consists of two semi-circular bars 1-in in

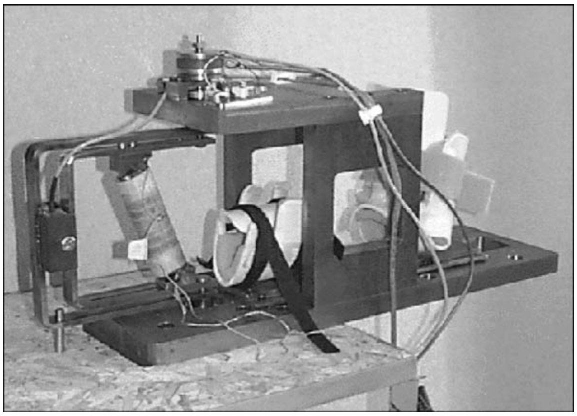

Fig. 1. Isokinetic wrist dynamometer.

diameter (total 4 cm) and two subminiature load cells (Sensotec® Model 13) mounted between the bars. It is also fixed at an angle of 25° from vertical for a neutral wrist deviation and has two sets of restraints to avoid motion of the lower and upper arm while exerting a maximum voluntary contraction.

Both load cells were wired to a STA-1800U screw terminal accessory. This terminal was connected to a DAS-1701AO board (Keithley Instruments, Inc.), installed in an IBM compatible Pentium PC. The data acquisition software, TestPoint™, was used to display and save the data. Both load cells were calibrated with known weights prior to the test. The data from load cells were saved at a sampling rate of 10 Hz.

2.3. Experimental design

The main dependent variables were the static grip strength and peak grip strength for the analysis of variance (ANOVA). In addition to static and peak grip strength, the number of points outside the $\pm 10\%$ bandwidth and the number of trials that would need to be repeated if the Caldwell regimen were recorded, as well as the duration of the build-up time and the maintained time which were also analyzed using the ANOVA. The independent variables for the $5 \times 2 \times 2$ within subject design for the ANOVA were the five instruction types, use of verbal encouragement, and use of visual feedback. Interactions for the dependent variables were also analyzed by performing an ANOVA and post-hoc (Tukey) tests were performed on all significant main effects and interactions.

The two levels of verbal encouragement were either with or without and the two levels of visual feedback were present or not. The five levels of instruction types used for exerting grip strength were as follows:

(1) Free instruction (FI): Squeeze the handle as hard as you can without jerk.
(2) Fast contraction and immediate release (FCIR): Squeeze the handle as fast as you can without jerking and release immediately when reaching the maximum force.
(3) Slow contraction and immediate release (SCIR): Squeeze the handle slowly and release immediately when reaching the maximum force. You should reach the maximum force in 2 s.
(4) Fast contraction and maintain (FCM): Squeeze the handle as fast as you can without jerking and maintain the maximum force over 4 s.
(5) Slow contraction and maintain (SCM): Squeeze the handle slowly and maintain the maximum force over 4 s. You should reach the maximum force in 2 s.

2.4. Procedure

After the experimenter measured the anthropometric dimensions and informed subjects of general testing methods, all devices were configured for the comfort of each subject. The arm posture recommended by the American Society of Hand Therapists (Fess and Moran, 1981) was followed to reduce the variation of forearm posture among subjects.

Free instruction trials for both encouragement and visual feedback conditions were tested first, in order to eliminate the influence of the other instruction types, while all other combinations of instructions, verbal encouragement, and visual feedback were randomized for each subject.

Subjects were told to perform the “free instruction” and practiced exerting this type of force once to be familiar with squeezing the handle and this method before the start of testing. After finishing the free instruction trials, subjects were informed about each of the other four instruction types in their randomized order and practiced each instruction type once before the test trial. A 2-min rest period was given to subjects between trials.

For the verbal encouragement trials, the experimenter sat beside the subject continuously while loudly shouting the word 'Go'. The alternative, no verbal encouragement, was just that; the experimenter, in a neutral tone, told the subject to start the exertion when he was ready.

Real-time visual feedback was given for half the trials using an application programmed using TestPoint™. When the subject was permitted to see the visual feedback, the experimenter activated the feedback button on the program. When subjects were not permitted to see their exertion level, however, they controlled the exertion time by watching the passing time using the same application without their exertion present.

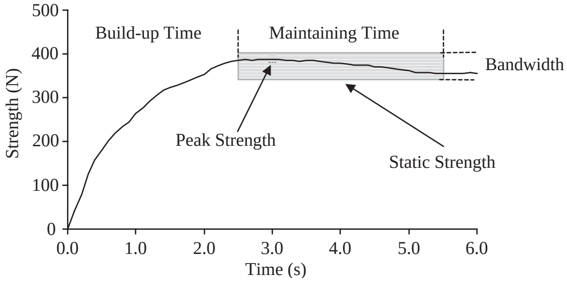

Fig. 2. Variables for data analysis.

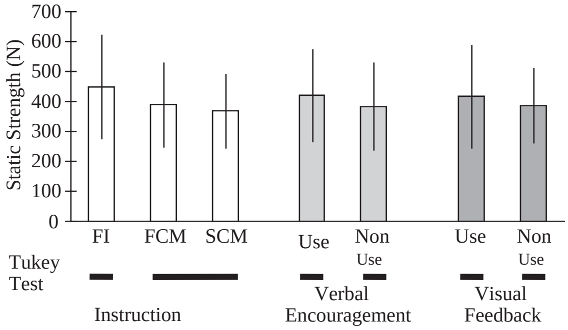

Fig. 3. Results of Tukey test on static grip strength.

3. Results

In order to identify the effects of instruction type, verbal encouragement, and visual feedback on the static grip strength, peak grip strength, time to obtain maximal strength, duration of maximal strength maintenance, and (steady-state) bandwidth while maintaining maximal strength were analyzed. The raw data for the single trial with areas showing how the dependent variable data were gathered is shown in Fig. 2.

3.1. Strength

Static grip strengths were calculated only from instruction sets of FI, FCM, and SCM in compliance with the Caldwell Regimen for the ANOVA because there were no maintaining periods in the instructions for FCIR and SCIR. However, peak strengths were extracted for each of the five instruction types.

Static strength: According to the results of the ANOVA on static strength, there were statistically significant main effects of instruction type ($F(2, 40) = 13.20$, $p = 0.0001$), verbal encouragement ($F(1, 20) = 20.13$, $p = 0.0002$), and visual feedback ($F(1, 20) = 4.46$, $p = 0.0475$) with no significant interaction effects.

As shown in Fig. 3, the results of post-hoc tests revealed that the FI (447.35 N) exertion type had the highest static grip strength and FCM (388.88 N) and SCM (368.21 N) had no mean difference. Static grip strengths were significantly higher with the use of both verbal encouragement and visual feedback.

Peak strength: The results of the ANOVA on the dependent variable of peak strength, identified that there were significant main effects of instruction type ($F(4, 80) = 6.86$, $p = 0.0001$), verbal encouragement ($F(1, 20) = 9.59$, $p = 0.0057$) and visual feedback ($F(1, 20) = 5.60$, $p = 0.0281$) and no significant interactions, which is similar to the results from the static strength analysis.

Following the ANOVA, post-hoc tests were performed on each significant effect and the results are shown in Fig. 4. The instruction types of FI

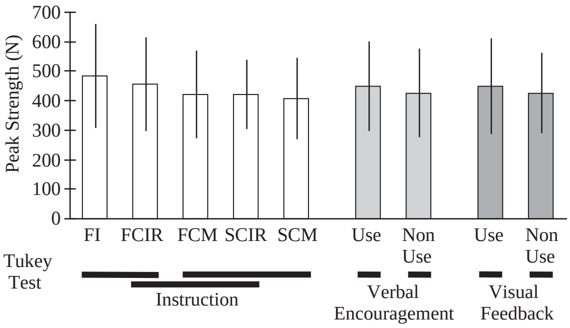

Fig. 4. Results of Tukey test on peak grip strength.

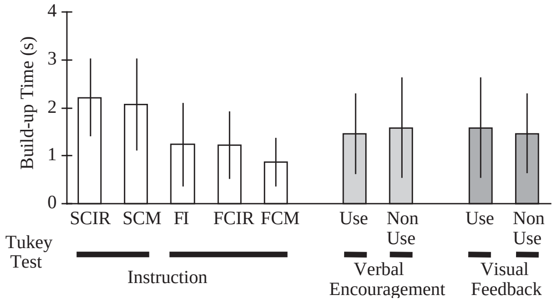

Fig. 5. Results of Tukey test on build-up time.

(483.45 N) and FCIR (456.75 N) showed higher peak grip strengths than the other instruction sets and the results of both verbal encouragement and visual feedback were similar to the results on static grip strength.

3.2. Time

The time to attain maximal strength (build-up time) and the duration of the maximal strength (maintaining time) were analyzed as dependent variables in an ANOVA. The purpose of analyzing these data was two-fold. First, we wanted to verify that the subjects followed instructions and that verbal encouragement and visual feedback had no effect on the performance of the fixed instruction trials. Second and more importantly, the build-up and maintenance periods of the free instruction were examined to see which instruction set, if any, it resembled.

Build-up time: ANOVA showed that there were significant main effects of instruction ($F(4, 80) = 32.77$, $p = 0.0001$), verbal encouragement ($F(1, 20) = 6.11$, $p = 0.0225$), and visual feedback ($F(1, 20) = 6.03$, $p = 0.0233$) and an interaction of between instruction type and visual feedback ($F(4, 80) = 2.90$, $p = 0.0270$).

As shown in Fig. 5, SCIR and SCM had around 2 s of build-up time and FI, FCIR, and FCM had around 1 s. In addition, build-up times were longer under the condition of non-use of verbal encouragement, while they were longer in the use of visual feedback. However, instruction types of FCIR and FCM had shorter build-up times with use of visual feedback than without it as shown in Fig. 6.

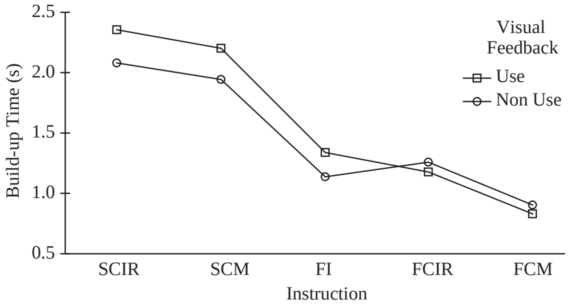

Fig. 6. Interaction between instruction and visual feedback on build-up time.

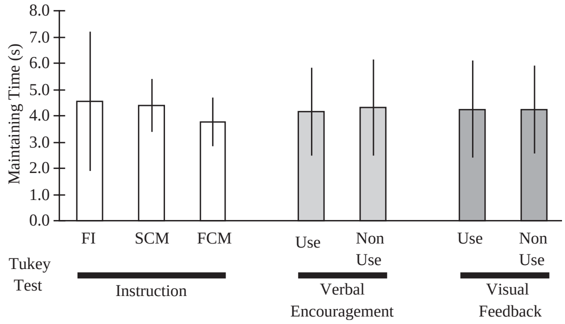

Fig. 7. Results of Tukey test on maintaining time.

Maintaining time: As shown in Fig. 7, there were no significant main effects or interactions for maintaining time. FI, SCM and FCM all had about 4 s of maintaining time and both verbal encouragement and visual feedback had no effect on maintaining time.

3.3. Bandwidth

During the 3 s (30 data) of maintaining time, the number of outlier data, which were outside the ±10% bandwidth criterion, were collected from each trial for the instruction types of FI, FCM, and SCM.

As shown in Fig. 8, there were no significant main effects or interactions for the independent variables of instruction type, verbal encouragement and visual feedback.

In addition, bandwidth and static strength were compared separately for each second, 1–4, during the maintaining time using only the trials of FCM and SCM without verbal encouragement and visual feedback because both factors had effects on static strength.

As shown in Table 1, more than 90% of data in the periods of both 1 and 2 s fell within the ±10% bandwidth criterion while fewer than 50% of trials in the periods of 3 and 4 s were within this criterion over all instruction types. Moreover, an ANOVA revealed that the only significant effect for the dependent variable of number of data points outside the bandwidth was period for static strength ($F(3, 60) = 16.87$, $p = 0.0001$) as well as the number of data that were outside bandwidth criterion ($F(3, 60) = 23.42$, $p = 0.0001$). As shown in Figs. 9 and 10, post-hoc tests showed that 1 s and 2 s were in the same group for both static strength and the number of data outside the criterion. In addition, the number of data points that fell outside the ±10%, while not significant, was larger for the FI and SCM than for FCM as were the variances. This leads to the conclusion that FCM may be more stable than either FI or SCM; therefore, preferred as a "static" exertion measure.

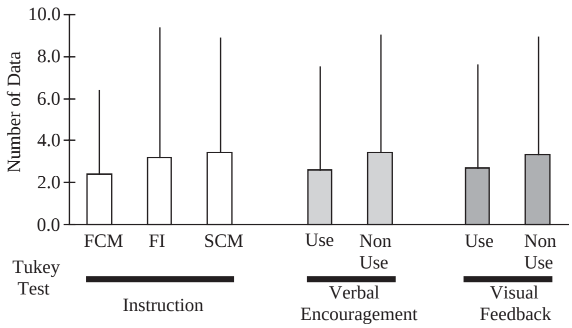

Fig. 8. Results of Tukey test on the number of data that were outside the ±10% bandwidth criterion.

Table 1
Bandwidth comparison for each period abiding by the ±10% bandwidth criterion

Period (s)	Percent of trials		Percent of number of data	
	FCM	SCM	FCM	SCM
1	95.24	90.48	99.52	98.10
2	61.90	66.67	91.43	93.33
3	33.33	47.62	83.97	88.57
4	23.81	38.10	82.26	86.07

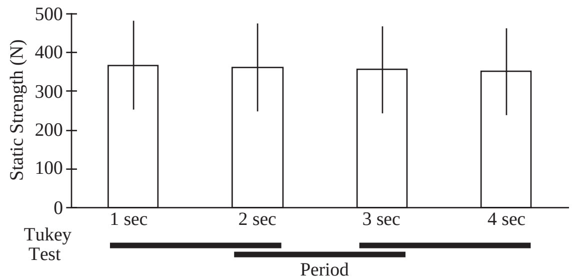

Fig. 9. Results of Tukey test on static grip strength for each period.

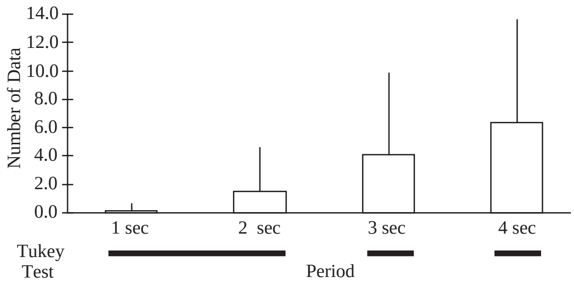

Fig. 10. Results of Tukey test on number of data that were outside the ±10% bandwidth criterion for each period.

4. Discussion

The factors of instruction type, verbal encouragement, and visual feedback had significant, but independent effects on static grip strength, peak grip strength, and build-up time to reach the maximal strength, but not duration of the maximal strength nor the bandwidth during the period of maintaining the maximal strength. The use of verbal encouragement and visual feedback increased static grip strength by about 9.7% and 7.7% more than non-use, and caused higher peak grip strength by about 5.6% and 5.2%, respectively. Therefore, it can be reaffirmed that both factors have positive effects on the motivation of subjects and raise the variation of strengths (Kroemer and Marras, 1980). Most strength test results are used to evaluate, analyze and redesign workplaces where neither motivation such as verbal encouragement nor knowledge of results such as visual feedback are present. Thus, to more closely simulate industrial conditions, both motivation and knowledge of results should be avoided. However, if "truly maximal" exertions are desired, both the independent factors; verbal encouragement and visual feedback should be employed during testing.

Maximal strength was reached faster when using verbal encouragement, while it was slower when using visual feedback. However, build-up times were faster in the instruction types of fast contraction like FCIR and FCM with the use of visual feedback, as was instructed.

According to the results of instruction types, FI caused the highest static and peak grip strengths as well as the largest variation for both strengths. The pattern of FI statistically resembles that of FCM, but had much larger variation of build-up time and maintaining time. One reason may be that subjects tended to exert strength over the whole period of the graph, 10 s, in the software programmed for a real-time visual feedback. Due to larger variations of strengths and times, the instruction of FI cannot be suggested for a strength measurement and a specific, consistent type of instruction should be utilized during the test (Berg et al., 1988; Williamson and Rice, 1992). However, if such testing occurs in an industrial environment, for example, it may resemble the FCM.

Although FCM was not statistically different from SCM in terms of static grip strength, it had second highest strength and was more consistent, with lower variations in build-up and maintaining times. Furthermore, FCM showed the fewest number of data that were outside the $\pm 10\%$ bandwidth criterion. With respect to peak strength, FCIR had the highest strength with the exception of FI; however, that was due to large variation. Both FCM and FCIR had around 1 s of build-up time.

When comparing bandwidth and static strength for each second, 1 through 4, using FCM and SCM instruction types, fewer than 50% of trials successfully followed $\pm 10\%$ bandwidth criterion and less than 90% of data fell into that bandwidth over the 3 s of maintaining time for both instruction types. Static grip strengths for the periods of 1 s and 2 s did not differ statistically and the number of data points that deviated from the 10% bandwidth were fewer than those in the other periods. Based on the results of FCM instruction and bandwidth comparison, this study suggests that 1 s of build-up time and 3 s of maintaining time are sufficient for measuring static handgrip strength, with averaging the data during the first 2 s of the maintained maximal period. Following this suggestion will not only reduce the variation of data that are outside the bandwidth criterion proposed by the Caldwell Regimen but also decrease the fatigue of forearm resulting from a large number of failed trials of strength measurement. For the measurement of peak grip strength, moreover, the instruction of FCIR may be recommended such that peak strength be reached in 1 s and immediate release of exertion of strength is sufficient.

The study accomplished by Berg et al. (1988) recommended that static pinch strength be averaged during the first 2 s. Therefore, it can be construed that averaged strengths of first 2 s of maintained strength are adequate for static strength measurements that are related to the hand.

This study quantified that the three factors of instruction type, verbal encouragement, and visual feedback and verified that they were significant effects. Therefore, they should not be used in strength measurement because of significant effects on both static and peak strengths if simulation of a workplace is desired. In addition, consistent instruction is necessary during all trials. Finally, it is suggested that a modified standard for measuring static and peak grip strengths which has a fast build-up rather than a slow build-up and then a short (3 s) maintained grip be adopted for the hand for the measurement of grip strength.

References

Berg, V.J., Clay, D.J., Fathallah, F.A., Higginbotham, V.L., 1988. The effects of instruction on finger strength measurements: applicability of the Caldwell Regimen. In: Aghazadeh, F. (Ed.), Trends in Ergonomics/Human Factors V. Elsevier Science Publishers, Amsterdam, pp. 191–198.

Caldwell, L.S., Chaffin, D.B., Dukes-Dobos, F.N., Kroemer, K.H.E., Laubach, L.L., Snook, S.H., Wasserman, D.E., 1974. A proposed standard procedure for static muscle strength testing. American Industrial Hygiene Association Journal 35, 201–206.

Chaffin, D.S., 1975. Ergonomics guide for the assessment of human static strength. American Industrial Hygiene Association Journal 36, 505–511.

Fess, E.E., Moran, C.A., 1981. Clinical assessment recommendations. American Society of Hand Therapists, Indianapolis, IN.

Kroemer, K.H.E., 1970. Human strength: terminology, measurement, and interpretation of data. Human Factors 12, 297–313.

Kroemer, K.H.E., Marras, W.S., 1980. Towards an objective assessment of the "maximal voluntary contraction" component in routine muscle strength measurements. European Journal of Applied Physiology and Occupational Physiology 45, 1–9.

Wilhelm, G.A., 1997. Design and validation of an isokinetic wrist dynamometer used to test the effects of gender, wrist position, exertion direction, wrist speed, and simultaneous grasp force on isokinetic wrist torque. Unpublished master's thesis, University of Nebraska, Lincoln, NE.

Williamson, T.L., Rice, V.J., 1992. Re-evaluation of the Caldwell Regimen: the effect of instruction on handgrip strength in men and women. In: Kumar, S. (Ed.), Advances in Industrial Ergonomics and Safety IV. Taylor & Francis, London, pp. 675–682.