

EFFECTS OF FORCE LEVEL AND TIME LAPSES AFTER TASK PERFORMANCE ON THE ACCURACY OF FORCE MATCHING IN A POWER-GRIP TRACKING TASK

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Abstract

Forces produced by the upper limb have been proposed as one of the dominant risk factors for distal upper limb musculoskeletal disorders. Force matching is a tool used to quantify these job demands. Previous work has determined that, for *static* tasks, force matching is more accurate at lower, than at higher, force levels, and that time lapses between task performance and force matching do not affect results. However, these results have not been investigated in *dynamic* tasks. The purposes of this study were to determine: 1) the effectiveness of force matching at quantifying hand demands during a dynamic gripping task, 2) if force level affects this accuracy, and 3) if time lapses between task performance and force reproduction influence force matching accuracy. Results showed that force matching accuracy is higher at low force levels, and is improved after time lapses of 3-5 minutes. Implications for the ergonomist are discussed.

Keywords: Force Matching, Risk Assessment, Upper Limb

L'EFFET DE LA FORCE ET DE L'INTERVALLE DE TEMPS APRÈS L'EXÉCUTION D'UNE TÂCHE DE PRÉHENSION DYNAMIQUE SUR LA PRÉCISION DE LA FORCE ÉQUIVALENTE

Résumé

Un des facteurs risque important proposé comme cause des nuisances musculo-squelettiques du membre supérieur est la force produite par ce dernier. Le concordement de force est souvent utilisé pour quantifier l'exigence de la tâche. Historiquement il a été démontré que le concordement de force est plus précis à un niveau de force moins élevé. Le lapse de temps entre la tâche et le concordement n'affecte pas le résultat. Cependant les tâches dynamiques n'ont pas été explorées. Le but de cette étude était de déterminer: 1) l'efficacité du concordement de force pour quantifier l'exigence d'une préhension dynamique, 2) si le niveau de force affecte la précision, et 3) si le lapse de temps entre la tâche et la reproduction de force influence la précision du concordement. Les résultats démontrent que le concordement est plus précis à un niveau de force moins élevé et qu'il s'améliore après un lapse de 3-5 minutes. La signification pour l'ergonomiste est adressée.

Mots clés: Concordement de force, évaluation de risque, membre supérieur

INTRODUCTION

Although the forces and moments produced by the upper limb are difficult to measure, they have been proposed as one of the dominant risk factors for distal upper limb musculoskeletal disorders (4). Thus, evaluation tools/methods that quantify the upper limb physical demands of workplace jobs are important elements in the prevention of upper limb injuries. Currently used tools requiring force quantification include the ACGIH Hand TLV (1), and the Strain Index (4), both of which require exerted forces as a fraction of maximum. Other force measures used include self-report in kgs and in % of maximal voluntary contraction (%MVC), and force matching (3). In a laboratory setting, Kingdon and Wells (3) found that for *static* tasks (the task involved maintaining a *single* grip force using an analog force transducer as a reference), force matching was the most accurate and consistent method of quantifying task demands at lower force levels. Self-report in kilograms did not give consistent results, while self-reporting in %MVC showed increasing consistency at higher force levels. However, most tasks performed in industry are not *static* in nature - they involve varying temporal patterns, and levels of effort. Investigation into force matching following a dynamic task was initiated by Kingdon and Wells (3) who reported that, when asked to match the 'greatest force exerted' during a three minute unstructured (no target force or temporal pattern provided) dynamic gripping task, participants most closely matched the mean peak force exerted during the task. However, investigation of the influence that force levels in a task have on the accuracy of force matching has not been performed.

Despite the previous lab studies, it is not always easy to accommodate force matching sessions at workstations. Often workers must be brought 'off-line' to perform the force reproduction tasks, resulting in a time lapse between task performance and force matching. Kingdon and Wells (3) found that introducing a time lapse between performance of a *static* grip force task and the force matching session did not significantly affect the resultant force matched values. However, investigation of the manner in which time lapses affect the accuracy of force matching in dynamic tasks has not yet been studied.

Thus, to inform decisions about when, and how to use force matching as a means of upper limb risk assessment, it is important to determine whether force level or time lapses affect the accuracy of the results. The purposes of the study were to determine: 1) the effectiveness of force matching at quantifying hand demands during a dynamic gripping task (an anisotonic isometric task, thus no segment accelerations), 2) if force level affects this accuracy, and 3) if time lapses between task performance and force reproduction influence force matching accuracy.

METHODS

Six healthy males and four females participated. The hand manipulation task consisted of cyclical isometric finger flexion contractions (gripping) of the dominant hand using an instrumented dynamometer, guided by a 1 Hz sinusoidal force target displayed on an oscilloscope, for two randomly assigned force conditions (low: 4.8 to 9.6 kg peak to peak, high: 14.4 to 19.2 kg peak to peak). The subjects performed the task for 30s, took a 30s rest, then repeated the task for another 30s (the end of this practice session was considered $t = 0$). At $t=30, 60, 180,$ and $300s$ the subjects were asked to match the *peak* force required in the gripping task for 4s with visual feedback from the oscilloscope removed. The force applied to the dynamometer was recorded at 2048 Hz with an A/D converter connected to a desktop computer. The force collected over the four second trial was averaged to determine the force matched value. Before each trial was collected, participants were asked to start

producing the appropriate force level. The trial was collected approximately five seconds later to eliminate start-up variability.

During analysis, the force matched value was compared to the actual peak value from the gripping task (9.6 or 19.2 kg, for the low and high force level conditions, respectively) to quantify the force matching accuracy.

RESULTS

Significant main effect differences, determined with a repeated measures ANOVA, existed for the measure of force matching difference (matched force – actual force) for the factors of force level condition, and time lapse after task performance.

The force matching difference was smaller at the low force condition compared to the high force condition (+0.44 kg vs. -1.61 kg, respectively) (see Figure 1). Participants *overestimated* the force requirements at the low force condition, and *underestimated* (to a greater degree) at the high force condition. The trend of more accurate matching at the low force level remained when actual/matched difference was normalized to the peak force requirement of the actual task (force matching difference/actual force * 100%), although the accuracy was within +/-10% at both low and high force levels (+4.4% vs. -8.4%, respectively). Larger actual/matched differences were observed 30 and 60s after task performance compared to measures taken 180 and 300s after the task (see Figure 2). Participants *underestimated* the force requirements during the first minute following task performance, and *overestimated* (to a lesser degree) the force requirements when time lapses grew larger (three and five minutes).

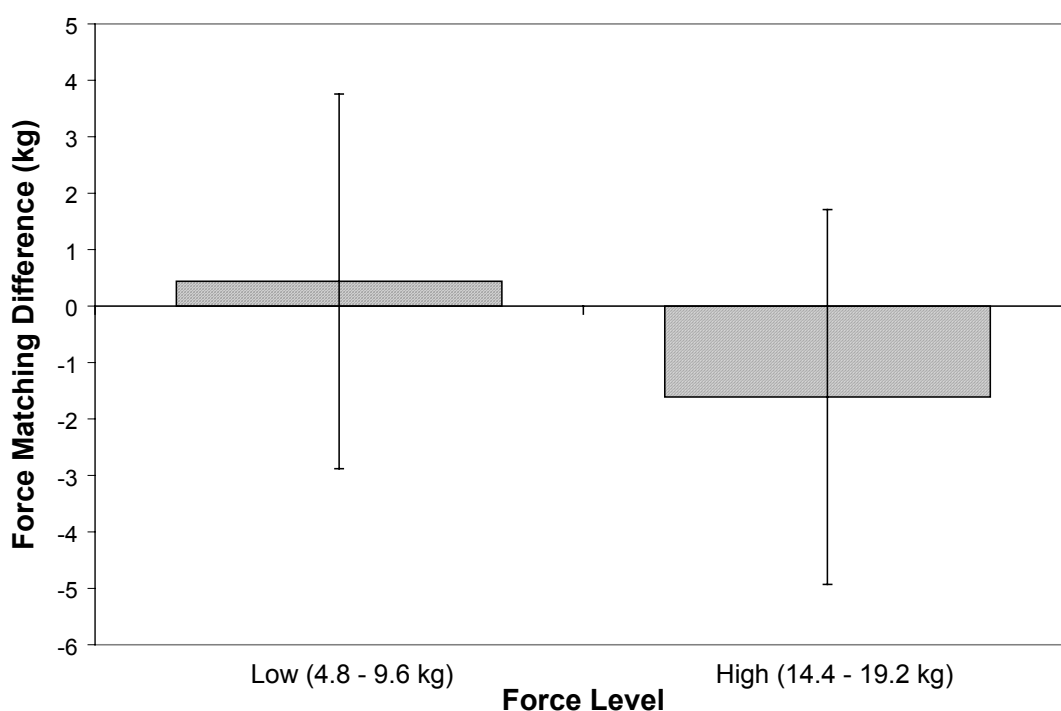


Figure 1: Force matching difference vs. force level condition for a hand grip task (all time lapse conditions averaged). Force matching error was significantly different for the high and low force levels.

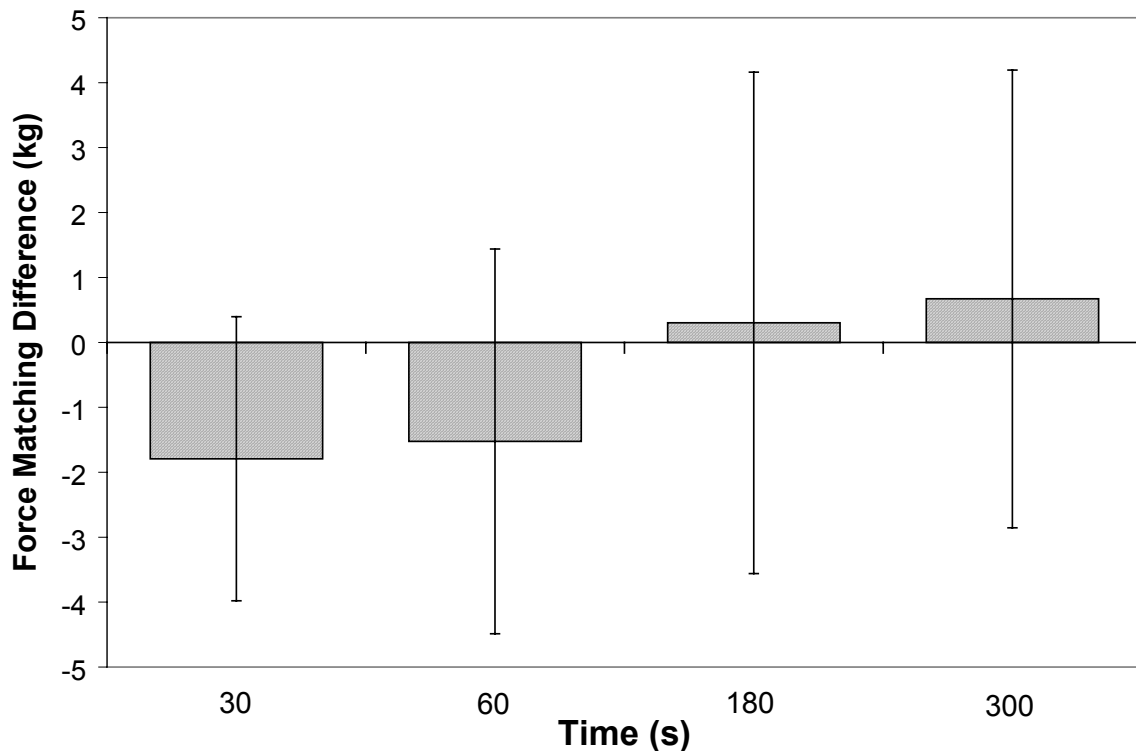


Figure 2: Force matching difference vs. time lapse for a hand grip task (force levels combined). Force matching errors 30, and 60 s after task performance were significantly different (and larger) than those from force matching performed at 180, and 300 s.

DISCUSSION

If an actual/matched difference of +/-10% is deemed acceptable, force matching appears to be an accurate method of quantifying physical demands of the upper limb in dynamic tasks. Similar to the static task force matching results of Kingdon and Wells (3), force matching was found to be more accurate at lower force levels for this dynamic gripping task. Numerous explanations for these observations exist. From a physiological perspective, perhaps the body can reproduce and grade forces more accurately at low force levels because more fast twitch fibers are activated at higher force levels. In contrast, perhaps a smaller proportion of total cognitive function is available to attend to accurate force reproduction when higher efforts are demanded of the upper limb musculature. Regardless of the mechanism responsible, ergonomists should be aware of the effect that task force level requirements have on the accuracy of force matching results.

In contrast to the Kingdon and Wells (3) findings, this study demonstrated that longer time lapses between task performance and force reproduction resulted in more accurate force matching. A possible explanation for this difference is that Kingdon and Wells (3) studied the participants' abilities to match forces from a static, isometric grip force task, while the subjects in this study were asked to reproduce the peak force demand from an anisotonic, isometric activity (arguably a more complex task). Perhaps the longer rest periods before the 180 and 300s trials allowed the subjects to mentally and physically prepare for the upcoming measures, resulting in smaller errors. These results are promising for the use of force

matching in industry in which time lapses between task performance and force-matching sessions are a distinct possibility. These results show that ergonomists should be aware of the influence of time lapses on accuracy of force matching results, and that the time lapses involved in bringing a worker 'off-line' to perform force reproduction appears not to jeopardize the accuracy of the force matching results for the force conditions evaluated in this study.

Much work remains to be done in the area of force matching as a tool for quantification of job demands. Ergonomists would greatly benefit if the optimal time delay between task performance and force matching was determined. In addition, further investigation should be done to determine the generalizability of these results to tasks that require different temporal patterns, and involve different muscle groups. Finally, further studies should be done to determine if these results can be replicated in settings outside of the laboratory. Specifically, how effective is force matching when the tool does not match the exact characteristics of the grip dynamometer/force transducer used to reproduce the force level?

In conclusion, force matching appears to be an accurate means of quantifying the job physical demands of the upper limb for dynamic tasks. Persons performing these force matching evaluations should consider factors such as level of force associated with the job in question, and time lapse between task performance and force reproduction when using force matching as a tool to quantify physical demands of the upper limb. Surprisingly, time lapses of 3-5 minutes between task performance and force reproduction may result in more accurate force matching values.

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