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Development of a Dynamic Biomechanical Model for Load Carriage: Phase III Part B:

Characterization of Load Control During a Human Trials Circuit

by

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Abstract

This work was undertaken in support of the research thrust “Development of a Dynamic Biomechanical Load Carriage Model”. The report describes human response characteristics, both objective and subjective, to a mobility circuit. The goals of the study were to examine the relationships among aerobic demand, performance time and load as well as the relationships between posture, shoulder and lumbar reaction forces and load. Eleven subjects volunteered for three aspects of the study: a maximal aerobic capacity test and two test days for each load carriage system, Pack C and Pack D. During the testing, subjects were instrumented with a heart rate monitor, accelerometers on the person and in the pack, and strap force sensors on the lower shoulder strap and on the waist belt. The circuit was completed five times in Battle Order of 5.5 kg, followed by randomized rucksack loads of 15.7 kg, 25.5 kg and 34.3 kg, as well as a self-selected maximal load. Subjects were asked to assume a pace they could sustain all day, given the load they were asked to carry. The circuit consisted of a number of marching and mobility tasks and was timed for all components of the circuit. Statistics were done using two- and three-way repeated measures ANOVAs. There were significant differences in timed performance and load ($p=0.001$) and between aerobic demand and load ($p=0.008$) but not between packs. This relationship held true for both laps and tasks. This resulted in a decrease in performance time of 19% and an increase in aerobic demand of 21% for the heaviest load compared to Battle Order. There was a significant increase in upper body and head lean angles and shoulder and lumbar reaction forces often between packs and always between loads. Posture changed by as much as 40% of the light weight’s postural lean angles with shoulder and hip reaction forces being 120% to 150% greater than the light load with the lumbar forces exceeding recommended limits. Subjective responses to various circuit demands and discomfort were also summarized. Future dynamic biomechanical modelling work should be directed toward integrating the model with the portable measurement system and so that the relationships between aerobic demand, shoulder and lumbar reaction forces and subjective discomfort can be determined for longer military exercises under variable loads.

Résumé

L’expérience en cause a été menée à l’appui du vecteur de recherche « Élaboration d’un modèle biomécanique dynamique de transport de charge ». Le rapport décrit les caractéristiques des réactions objectives et subjectives d’une personne durant le parcours d’un circuit de mobilité. L’étude avait pour but d’examiner les relations entre la demande aérobie, le temps de performance et la charge ainsi que celles entre la posture, les forces de réaction lombaire et des épaules et la charge. Onze personnes se sont portées volontaires pour trois aspects de l’étude : un test pour mesurer la capacité aérobique maximale et deux jours de tests avec chaque dispositif de transport de charge, soit le sac à dos C et le sac à dos D. Durant les essais, les sujets portaient un moniteur de fréquence cardiaque et un accéléromètre (un autre accéléromètre a été fixé au sac à dos), et des capteurs de force ont été posés sur la partie inférieure des sangles d’épaule et sur la ceinture. Ils ont parcouru le circuit cinq fois, d’abord dans l’attirail de guerre de 5,5 kg, puis avec un sac à dos contenant des charges aléatoires de 15,7 kg, de 25,5 kg et de 34,3 kg ainsi qu’une charge maximale de leur choix. On a demandé aux sujets d’adopter une cadence qu’ils pouvaient maintenir toute la journée, compte tenu de la charge qu’ils devaient transporter. L’épreuve comprenait de la marche et en un certain nombre de tâches de mobilité, toutes les étapes de l’épreuve étant chronométrées. Des statistiques ont été établies en effectuant une analyse de variance (ANOVA) à mesure répétée de deux et de trois variables. Des écarts considérables ont été notés pour la durée de la tâche et la charge (p = 0,001) et pour la consommation aérobique et la charge (p = 0,008), mais pas entre les différents sacs à dos. Cette relation s’appliquait tant aux circuits qu’aux tâches. Une comparaison effectuée avec l’attirail de guerre a permis de constater une diminution de la performance de 19 % en durée avec la charge la plus lourde, et une augmentation de 21 % de la consommation aérobique. Une augmentation considérable a été remarquée au niveau de l’angle d’inclinaison du haut du corps et de la tête ainsi que des forces de réaction des épaules et de la région lombaire, souvent entre les différents sacs à dos et toujours entre les charges. Par rapport à la charge la plus légère, l’angle d’inclinaison posturale a augmenté de plus de 40 %, et les forces de réaction au niveau des épaules et des hanches ont augmenté de 120 à 150 %, ce qui constitue un dépassement des limites recommandées pour les forces lombaires. Le rapport donne également un résumé des réactions subjectives aux diverses exigences du circuit et de l’inconfort ressenti. Les futures recherches sur le modèle biomécanique dynamique devraient être orientées vers l’intégration du modèle au système de mesure portatif afin de permettre la détermination de la consommation aérobique, des forces de réaction lombaire et des épaules et l’inconfort subjectif pour des exercices militaires plus longs avec diverses charges.

Executive Summary

This work was undertaken in support of the research thrust “Development of a Dynamic Biomechanical Load Carriage Model”. This document describes the human response characteristics, both objective and subjective, to a mobility circuit. The goal of the study was to examine the decrement in performance with load and pack type (Packs C and D). Eleven subjects volunteered for three aspects of the study: a maximal aerobic capacity test and two test days for each load carriage system, Pack C and Pack D. Prior to the study, subject’s maximal oxygen consumption and maximal heart rates were elicited within the 20 m Shuttle Run in order to determine percent of aerobic capacity used during the circuit. During the testing, subjects were instrumented with a heart rate monitor, accelerometers on the person and in the pack, and strap force sensors on the lower shoulder strap and on the waist belt. The circuit was completed five times in Battle Order of 5.5 kg, followed by randomized rucksack loads of 15.7 kg, 25.5 kg and 34.3 kg, as well as a self-selected maximal load. Subjects were asked to assume a pace they could sustain all day, given the load they were asked to carry. The circuit consisted of a number of marching and mobility tasks and was timed for all components of the circuit.

Relationship of aerobic capacity and circuit duration to load. Normally other studies have controlled the workload or pace and observe the response of aerobic demand to load. In this study we varied both load and pace to see how subjects adjusted without the pressure of being forced to adjust oxygen consumption as their only method of control. Using two and three-way repeated measures ANOVA with packs, loads and laps, there was no significant difference between packs. However, with regard to aerobic demand, there was a significant difference between loads (p=0.001), between laps (p=0.001) and between tasks (p=0.001). There was a decrease in performance time for each task with load (p=0.001) but not between packs. In comparison to Battle Order, there was a 5% to 15% drop-off in time during laps, which was significant by load (p=0.005) and almost by pack (p=0.06). Similarly, the drop off in performance for task times was 11.6% to 29.2% for 15.5 kg to 34.3 kg respectively.

The subjects’ aerobic responses differed significantly by load during the tasks (p=0.004), however, only the 34.4 kg load caused greater than a 15% increase in MVO_2 from the Battle Order baseline. The aerobic demand was 55% MVO_2 at Battle Order and rose to 60% MVO_2 during the 34.4 kg load. During the laps, aerobic demand increased around 15% for the intermediate loads and 27.1% during the 34.4 kg load. In 16/20 cases, subjects tried to keep oxygen consumption constant and accommodate by moving at a slower pace. The four subjects who were of varying fitness levels, allowed oxygen consumption to climb and tried to maintain a constant pace throughout all trials. In each case, this was their first day of testing and they did not repeat this pattern on the second day.

Relationship of subjective responses to load. Within the report, subjects were queried about their pack control, balance mobility and agility during the tasks with summary questionnaires at the end of the circuit. There was a significant difference between packs (p=0.002) and between loads (p=0.001). Pack C was preferred over Pack D on almost every variable. The pack preference was less convincing for comfort where overall comfort, shoulders and neck, waist and low back and thermal comfort were assessed. This was not surprising as the same shoulders straps, frame sheet and waist belts were used for both Pack C and Pack D. In a 6 point subjective questionnaire, the highest average score was 4 or moderate discomfort. There was a drop off in comfort of 12.5 % from 5.6 to 4.9 over this short course. It was expected that subjective ratings would be greater when task durations are lengthened to more military-like distances. Subjective ratings are an important aspect of pack and load evaluation. It was concluded that there were more evaluative questions than necessary as the final questionnaires after circuit completion tended to capture the depth of the subjects' perceptions better than individual task based assessments. In future studies fewer assessments would be appropriate.

Relationship between shoulder and lumbar reaction forces and load. Each subject was asked to stand perpendicular to a digital camera and one photograph was taken per load. Knowing the weight in the pack, dimensions of the pack and the lean angle of the soldier, it was possible, using static biomechanical models by McNeill (1996) and Pelot (1998), to determine the shoulder and lumbar reaction forces needed to counterbalance the weight of the pack. In previous reports, Stevenson et al. (1995) recommended that, to reduce discomfort to a minimum, the shoulder reaction forces should be 145 N/shoulder or 290 N for both shoulders and 135 N for lumbar reaction force. For the shoulders, there was no significant difference by pack but there was between loads (p=0.001). For Pack C the shoulder reaction force during the heaviest load was 280 N and for Pack D was 355 N. These were increases of 120% to 150% over the light load. For the lumbar reaction forces, there was a significant difference between packs (p=0.005) and between loads (p=0.001). Pack C averaged 300 N and Pack D averaged 350 N. Since the original guideline was developed around a 6 km march with 34 kg, it is not surprising that soldiers would be able to tolerate higher load for shorter durations. It appears that the recommended limit for the shoulders may be correct with a good pack design as even the 34.4 kg load was under the recommended limit of 290 N. However, the recommended lumbar limit may be too low at 135 N. Few soldiers complained about discomfort in this region, perhaps due to good pack design. The lumbar reaction force needs to be re-evaluated in light of these findings.

Relationship between subjective discomfort and body reaction forces. In previous reports, the recommended guidelines were based on the relationship between discomfort and shoulder and lumbar reaction forces. There were few complaints relative to longer distances of load carriage; nonetheless a regression analysis was repeated. The level of discomfort at the heaviest load averaged 4+ (moderate discomfort) on a 9-point scale. The relationship was strong (r^2 = .91) for the shoulder reaction force (SRF) with less explanatory power (r^2=.61) for the lumbar reaction force (LRF). Combined SRF across both packs were at 290 N at the 34.4 kg load and LRF averaged 330 N. One concern with accurate interpretation of these data was the shortness of the circuit in comparison to typical military missions.

It is hypothesized that there will be a relationship between the biomechanical variables, duration of a task and load. It is also hypothesized that there will be a strong relationship between psychophysical measures and biomechanical measures that are both affected by load and pack design. These relationships will allow the development of a biomechanical factor that can be used in the establishment of a load conditions limit that is appropriate for different types of missions. It is recommended that field trials be commissioned to take the same measures, as well as aerobic demand measures, under military marching pace for longer marches with various loads: such as, a) length of the annual army fitness test, b) on a four hour and/or c) all day mission. From these data, biomechanical tolerance data can be developed for the average soldier.

Sommaire

L’expérience en cause a été menée à l’appui du vecteur de recherche « Élaboration d’un modèle biomécanique dynamique de transport de charge ». Le rapport décrit les caractéristiques des réactions objectives et subjectives d’une personne durant le parcours d’un circuit de mobilité. L’étude avait pour but d’examiner la diminution de la performance en fonction de la charge et du type de sac à dos (sacs C et D). Onze personnes se sont portées volontaires pour trois aspects de l’étude : un test pour mesurer la capacité aérobique maximale et deux jours de tests avec chaque dispositif de transport de charge, soit le sac à dos C et le sac à dos D. Avant le début de l’expérience, la consommation d’oxygène et la fréquence cardiaque maximales des sujets ont été sollicitées par une course en navette de 20 m afin de déterminer la capacité aérobique, en pourcentage, utilisée durant le parcours du circuit. Pour les essais, les sujets ont été munis d’un moniteur de fréquence cardiaque et d’un accéléromètre (un autre accéléromètre a été fixé au sac à dos), et des capteurs de force ont été posés sur la partie inférieure des sangles d’épaule et sur la ceinture. Ils ont parcouru le circuit cinq fois, d’abord dans l’attirail de guerre de 5,5 kg, puis avec un sac à dos contenant des charges aléatoires de 15,7 kg, de 25,5 kg et de 34,3 kg ainsi qu’une charge maximale de leur choix. On a demandé aux sujets d’adopter une cadence qu’ils pouvaient maintenir toute la journée, compte tenu de la charge qu’ils devaient transporter. L’épreuve comprenait de la marche et un certain nombre de tâches de mobilité, toutes les étapes de l’épreuve étant chronométrées.

Relation entre la charge, la durée de l’épreuve et la capacité aérobique. Habituellement, durant d’autres expériences, la charge ou la cadence étaient contrôlées pour observer la demande aérobie en fonction de la charge. Dans cette expérience, on a modifié la charge et la cadence pour déterminer la méthode d’adaptation adoptée par les sujets, sans les contraindre à réguler leur consommation d’oxygène comme seul moyen d’ajustement. Une analyse de variance à mesure répétée de deux et de trois variables (sacs à dos, charges et nombre de tours) a permis de constater qu’il n’y avait pas de différence significative entre les sacs. Cependant, il y avait un écart considérable dans la demande aérobie entre les différentes charges ($p = 0,001$), entre les tours ($p = 0,001$) et entre les tâches ($p = 0,001$). La durée d’exécution de chaque tâche augmentait pour chaque charge ($p = 0,001$), mais il n’y avait pas d’écart entre les sacs à dos. Comparativement à l’attirail de guerre, la durée d’exécution de chaque tour variait de 5 % à 15 %; l’écart était considérable entre les différentes charges ($p = 0,005$) et faible entre les différents sacs ($p = 0,06$). De plus, l’augmentation du délai d’exécution des tâches variait de 11,6 % à 29,2 % pour les charges de 15,5 kg et de 34,3 kg, respectivement.

La consommation aérobique des sujets en fonction de la charge a subi des variations considérables ($p = 0,004$) durant les tâches; cependant, seule la charge de 34,4 kg a entraîné une augmentation de la MVO_2 supérieure à 15 %, comparativement à la valeur de base obtenue avec l’attirail de guerre. La demande aérobie correspondait à 55 % de la MVO_2 avec l’attirail de guerre pour passer à 60 % durant le transport de la charge de 34,4 kg. À chaque tour, la demande aérobie augmentait d’environ 15 % avec les charges

intermédiaires, et de 27,1 % avec la charge de 34,4 kg. Seize des vingt sujets ont essayé de maintenir une consommation d’oxygène constante et de s’adapter en diminuant leur cadence. Les quatre autres sujets, dont le niveau de condition physique variait, ont laissé leur consommation d’oxygène grimper et ont essayé de maintenir une cadence constante durant tous les tests. Dans chaque cas, ils ont procédé de cette façon le premier jour des essais, mais non le deuxième jour.

Relation entre les réactions subjectives et la charge. Aux fins du présent rapport, on a posé des questions aux sujets durant les tâches sur la maîtrise des sacs à dos, l’équilibre et l’agilité et on leur a remis un questionnaire sommaire à la fin de l’épreuve. L’écart était considérable entre les sacs (p = 0,002) et entre les charges (p = 0,001). Pour la majorité des paramètres, les sujets préféraient le sac C au sac D. La préférence était moins nette au niveau du confort; l’évaluation portant sur le confort global, le confort au niveau des épaules et du cou, le confort au niveau de la taille et du bas du dos et le confort thermique. Ce résultat n’est pas surprenant, étant donné que les sacs C et D étaient munis des mêmes sangles d’épaules, armature et ceinture. Le résultat moyen le plus élevé du questionnaire subjectif à 6 points était de 4, ce qui représente un inconfort modéré. Le niveau de confort a chuté de 12,5 % durant le court trajet, soit de 5,6 à 4,9. On s’attend à obtenir des cotes subjectives plus élevées lorsque la tâche sera prolongée à des distances militaires. Les cotes subjectives sont un aspect important de l’évaluation des sacs à dos et des charges. On a conclu qu’il n’était pas nécessaire de poser un si grand nombre de questions durant l’évaluation, car les questionnaires finaux présentés à la fin de l’épreuve permettaient de mieux saisir la perception des sujets que les évaluations individuelles de chaque tâche. Dans les prochaines expériences, le nombre de questions d’évaluation devrait être réduit.

Relation entre les forces de réaction aux épaules et à la région lombaire et la charge. On a demandé à chacun des sujets de se tenir perpendiculaire à un appareil-photo numérique, et une photo par charge a été prise. En connaissant le poids et les dimensions du sac ainsi que l’angle d’inclinaison du soldat, on a pu déterminer les forces de réaction aux épaules et lombaires nécessaires pour contrebalancer le poids du sac en utilisant les modèles biomécaniques statiques de McNeill (1996) et de Pelot (1998). Dans des rapports précédents, Stevenson et al. (1995) a recommandé que, pour réduire l’inconfort au minimum, les forces de réaction des épaules devraient être de 145 N par épaule, ou de 290 N pour les deux épaules, et de 135 N pour la région lombaire. En ce qui a trait aux épaules, il n’y avait pas d’écart significatif entre les sacs, mais il y en avait entre les charges (p = 0,001). Pour le sac C, la force de réaction des épaules durant le transport de la charge la plus lourde était de 280 N, et pour le sac D, elle était de 355 N. Cela représentait des augmentations de 120 % à 150 % par rapport à la charge légère. En ce qui a trait à la force de réaction lombaire, les écarts entre les sacs (p = 0,005) et entre les charges (p = 0,001) étaient considérables. La moyenne pour le sac C était de 300 N, et pour le sac D, elle était de 350 N. Étant donné que la valeur originale a été établie avec une charge de 34 kg sur un parcours de 6 km, il n’est pas surprenant que les soldats soient capables de tolérer une charge plus lourde pendant des périodes plus courtes. Il semble que la limite recommandée pour les épaules est correcte pour un sac bien conçu, car même avec la charge de 34,4 kg, la valeur était inférieure à la limite recommandée de

290 N. Cependant, la limite recommandée de 135 N pour la force de réaction lombaire pourrait être trop basse. Peu de soldats se sont plaints d'inconfort dans cette région, peut-être en raison de la bonne conception du sac. La force de réaction lombaire doit être réévaluée en fonction des résultats obtenus.

Relation entre l'inconfort subjectif et les forces de réaction corporelles. Dans les rapports précédents, les valeurs recommandées étaient fondées sur la relation entre l'inconfort et les forces de réaction des épaules et lombaires. Peu de plaintes ont été enregistrées pour le transport de charges sur de plus grandes distances; toutefois, une analyse de régression a été répétée. Le niveau d'inconfort moyen pour la charge la plus lourde était de >4 (inconfort modéré) sur une échelle de 9. La relation était grande pour la force de réaction des épaules (SRF)(r^2 = 0,91), et moindre (r^2=0,61) pour la force de réaction lombaire (LRF). Pour les deux sacs, la SRF combinée était de 290 N avec la charge de 34,4 kg, et la LRF moyenne était de 330 N. Une préoccupation relative à l'exactitude de l'interprétation de ces données est la distance de l'essai par rapport à celle des missions militaires types.

On suppose qu'il existe une relation entre les variables biomécaniques, la durée d'une tâche et la charge. On fait également l'hypothèse que la relation soit grande entre les mesures psychophysiques et les mesures biomécaniques qui sont influencées par la charge et la conception du sac. Ces relations permettront d'établir un facteur biomécanique qui pourra servir à déterminer une limite de charge applicable à différents types de missions.

Acknowledgements

I would like to acknowledge the contribution of many individuals who have make this research possible. First, LCol Linda Bossi of the Defence Research and Development Canada – Toronto who has placed her trust and support in us in our desire to improve the design and testing of products for improved safety and performance. Captain Nathalie Sleno was a key facilitator in finding military subjects and working with Warrant Officer T.J. Whitehead from the Hastings and Prince Edward Regiment.

To prepare the Queen's Bews Gym as a test site, Gord Bullock was helpful in making difficult problems seem easy and Greg McCauley and his equipment staff handed out lots of equipment with no complaints. Nike Mitsiopoulos from the Fitness Centre prepared the assistant for 20 m shuttle run testing and helped interpret these data and Ken Hall accumulated heart rate monitors like they were going out of style and Onno Oosten who fixed strain gage after strain gage as we went through the learning curves.

The biggest thank you goes to the research assistants who collected data until they dropped. I am speaking specifically of Lindsay Hadcock, Josh Good, Mohammad Abdoli and Jason Dunford. These folks were construction and demolition experts as well as research scientists. The subjects, who were students and reservists, were also most gracious as they performed each task to the best of their potential. I will single out Scott Lynn and Reilly Musselman who, as the first pilot subjects, had to face our learning process as well.

My colleagues on this project, as usual, always came through in the clutch. Evelyn Morin and Sue Reid spent many sleepless nights struggling with the final design and workings of the portable measurement system and Tim Bryant came by to save the day, as usual.

In data analysis, and over the Christmas holidays, Christine Barrick was busy entering subject data into the computer. The undergraduate 453 students were willing to learn and create a draft look at the biomechanical model data. It was here that we discovered shortcomings and made the necessary revisions. The main engine for data processing, graphing and setting up of statistics data tables was our impressive KCVI high school co-op student Ian Devenney. Thanks a bunch, Ian. And to make the final push to completion, NSERC summer student, Julie Kelly added the final edits and literature to put this report in context.

As can be seen from the above line-up of contributors, no project of this magnitude can be done alone. It has been a true team effort and I wish to thank all who helped the principal investigators reach this stage of understanding about the biomechanics and physiology of human load carriage.

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1. Introductions

1.1 Dynamic Biomechanical Model

Defence Research and Development Canada - Toronto (DRDC) approved the development of a dynamic biomechanical model (DBM) of human load carriage in order to improve understanding and provide more accurate measurement of factors contributing to human load performance and mobility. The approach to this problem was delineated in an earlier report entitled Proposed Long Range Plan for Research and Development of Dynamic Load Carriage Modeling (PWGSC # W7711-0-7632-01).

Figure 1 is a pictorial look at a dynamic biomechanical modeling (DBM). The task of model a backpack involves using the pack and body parameters as inputs to the model. For pack parameters, we constructed a moment of inertia platform that could provide the centre of gravity and the moment of inertia of the pack (PWGSC Contract # W7711-0-7632-01, 2001). This moment of inertia platform was used in this Phase 3 of the project. Another task that was completed in Phase 1 was a full body mapping of the 50th percentile male mannequin from the Load Carriage Simulator (Phase I-6a(5)). This mapping was also used in Phase 3 as the body parameters input to the DBM Version#1. The pack characteristics and person's body shape must also be input into the model.

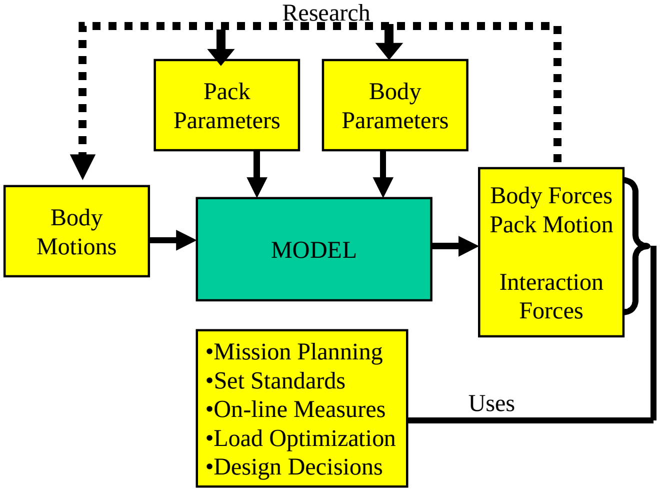

Figure 1 Visual depiction of steps needed to create a biomechanical model

Once the pack and person components have been defined, it is necessary to input a typical forcing function that describes the person's and pack's response during marching and typical soldier mobility tasks. There are two ways to acquire body motions: with the LC Simulator and using accelerometers on humans. The first set of body motions (3) were generated using the LC Simulator. To accomplish this, the LC Simulator Fastrak programs were changed to have three inputs, a fixed reference system, the LC Simulator and the pack. Using these three sensors it is possible to determine pack-person relative motion, and person-ground relative motion. In this way, a non-moving ground reference sensor was added to the set-up so that the motion characteristics could be programmed into the DBM as the forcing function that would elicit a measured pack response. The development of this aspect was in Phase 1-6(1). Once the final model is built, missions personnel will be able to accomplish many added features, such as better mission planning based on anticipated rest periods, setting more accurate standards, and on-line measures of predicted forces and rest periods.

1.2 Body Motions as Input to the DBM Model

To build the DBM, it is best to move from expected motions, such as with the LC Simulator, to more complex human motions, such as those generated by subjects during walking and load control circuits. Unlike the LC Simulator, where displacement measures can be used to acquire motion data for a mobility circuit, it was necessary to use devices that allowed the person to move freely. For this study, tri-axial accelerometers recorded motions directly into a portable measurement system. One accelerometer was fixed to the pack and the other onto the person so the relative accelerations could be compared. These data will allow us to see the actual pack responses to human motions during the circuit. These data are vital inputs to the DBM model as it allows for validation of complex human motion characteristics that could occur in a military situation.

This report focuses on Human Trials, but does not address the output data from the accelerometers. These complex waveforms will become part of validating future DBM and a strategy for their analyses is part of the portable system report on W7711-0-7632-05. Instead this report deals with more basic Human Trials information that relates to energy demands, load, pack type and task conditions and the subjective responses to these conditions. This report provides a background overview of the trials themselves and a number of subjective and objective responses to increasing load. Hopefully, these data can be used in several ways: to validate objective measures, to examine the recommended criteria for tissue tolerance limits in load carriage, to examine drop-off in performance as a result of increased load, and to study the biomechanical factors related to a load carriage limit.

1.3 Justification for Approach to Human Trials

Load carriage is a common activity in leisure and in specific occupations such as the military. There are currently no guidelines to limit the exposure of users to potentially harmful pressures and lumbar forces. These harmful pressures and forces are often due to the load or duration of load carriage but the load carriage system itself also has a modulating effect on shoulder and lumbar forces. (Stevenson et al., 2001; Bryant et al., 2001). When tissue tolerances are exceeded, there can be injuries to the skin at the shoulders and waist and chronic injuries to the back and brachial plexus (Knapik et al., 1996; 2001). When the dynamic biomechanical model is developed, it will predict tissue loading during various activities for a range of designs and loads. The human trials collected in this phase can serve to validate the model.

There are numerous military studies that report on the effects of heavy load carriage from a physiological perspective (Borghols, 1978; Haisman, 1988; Knapik et al., 1996; Myles and Saunders, 1979). Many of these studies with military subjects report loads in excess of 40 kg since that level of loading is indicative of some marching conditions. The heaviest loads reported in the recent literature were during the British assault on the Falkland Islands where the average weight per solider was 68 kg (McGaig and Gooderson, 1986). Under current Canadian issued equipment, a MAW gunner and radio operator in full marching gear are expected to carry 70.4 kg and 66.2 kg respectively. The yearly Canadian Army minimal fitness test requires soldiers to carry 24.5 kg (plus helmet and rifle) a distance of 13 km in 2 ½ hours. This is followed by each soldier carrying a 'wounded' soldier a distance of 100m. Based on this evidence, we know that it is important to test soldiers under typical conditions they may experience in the field. Hence, payloads of Battle Order kit, 10 kg, 20 kg and 30 kg will be used in this study, given the frequent expectations of military personnel.

Use of a circuit to examine military task performance is common in the scientific literature (Haisman, 1988; Martin and Nelson, 1986). Circuits have been used to study different load masses (Pierrynowski et al., 1981); different load locations (Soule et al., 1979), different pack designs (Stevenson et al., 2001) as well as examining the performance based on gender under set or variable loads (Frykman et al., 2001; Pandolf et al., 2001). Typically, subjects are asked to perform the task or tasks and results are determined either objectively (timed events) or subjectively using opinion and discomfort (pain) visual scales. In our previous studies in 1995 and 1997, we had soldiers wear four packs (one pack per hour) for four hours while performing circuit tasks (Stevenson et al., 1995) or wear one pack for approximately four hours performing the same tasks with marching 6 km interspersed between tasks (Stevenson et al., 1998). During that testing period, soldiers were sweaty and somewhat tired, but no subject was injured or handicapped physiologically on subsequent test days. All tests were considered to be normal or less than the demands place on soldiers during regular military exercises. For this study, because this series of tests will involve a number of different load conditions, soldiers will wear different payloads (Battle Order, 10kg, 20 kg, 30kg, self-selected kg) in packs for approximately 20 minutes with a minimum of 30 minutes of rest between each trial.

Another common strategy within the scientific literature is to use a psychophysical approach to evaluating a person's maximum acceptable (self-selected) load weight. This psychophysical approach is a commonly used approach to create normative databases for lifting tasks (Snook, 1978; Mital, 1984; Ayoub et al., 1989; Snook and Cirello, 1991). This approach is also the basis of the BORG Scale of perceived exertion and other human perception tests such as: hearing test, sight tests and pain tolerance tests. The concept, originally proposed and validated by Stephens in 1962, is to keep all conditions, except one, the same and allow the subject to alter that one variable or give an opinion about that variable. For example in lifting studies, the task conditions (lift height, lift starting point, frequency of lifts and box to be lifted) are kept constant and the subject is asked to adjust the unknown weight in the box such that it is their maximum acceptable load condition without risk of injury during the work duration scenario (1, 2, 4, 8, 12 hours). This approach has been validated by physiological methods (Garg and Saxena, 1979 Mital, 1983) for lifting. There are no reports of injuries during data collection with this approach. In this study, it is also hypothesized that soldiers will self-select a load that maximizes human performance and optimizes subjective discomfort. As a result, it may be possible to use the subject's self-determination of acceptable discomfort as a criterion for a tissue tolerance limits.

2. Purpose of this Study

For the biomechanical modelling project, it was hypothesized that load and pack design would have an effect on pack motions, body forces and subjective responses of subjects to biomechanical and physiological factors that were required for performance on a standardized mobility circuit. The objective of this study was to begin to address the issue of characterization of load control during a mobility circuit as it related to: circuit time, energy demands, load, pack type, mobility tasks and subjective evaluations of performance. The two main outcome measures were to determine where there was a 15% decrement in performance and what were the subjective responses that suggested an acceptable tissue tolerance limit. The specific questions to be addressed are:

1) What is the effect of load on performance time on a mobility circuit and energy demands for the Canadian Clothe the Soldier Pack called Pack C?
2) Does this relations differ based on pack design (Pack C and Pack D)?
3) To what extent does performance decrease due to load and pack design?
4) How do subjects rank their discomfort with increased load and pack design?
5) What is the effect of load on body posture and shoulder and hip reaction forces for the Canadian Clothe the Soldier Pack called Pack C?
6) Does this relations differ based on pack design (Pack C and Pack D)?
7) What is the relationship between subjective discomfort and the shoulder and lumbar reaction forces?

These objectives are important to understand soldier responses to differing loading conditions and to determine where the main decrements in performance occur. The study design also addresses a number of biomechanical and physiological factors that could assist TTCP HUM TP6 (KCA-8) in developing a Standard Agreement (STANAG) on military load carriage. Queen's has been a major Canadian contractor in developing standardized assessment tools for load carriage based on biomechanical factors. We hypothesize that it may be possible to develop a Load Carriage Limit (LCL) Guideline that is based on mission factors and physiological, biomechanical, demographic and readiness factors of the soldiers. We also hypothesize that the DBM can be validated with data taken during the mobility circuit and Marching Order conditions in Phase 4.

3. Methodology

3.1 Subject Selection

The scientific authority at DRDC was able to recruit 12 military subjects as volunteers from the Hastings and Prince Edward Regiment. The Ergonomics Research Group recruited an additional six volunteers from Queen's University. All subjects were required to have better than average fitness levels and have experience with backpacking.

Testing took place during December 2002 in the Physical Education Centre of Queen's University. Each subject was given a briefing about the study followed by a request for them to read an information sheet and sign an ethics consent form. All subjects were asked to keep a form as well. Then, subjects were asked to complete a Par-Q form developed by the Canadian Society for Exercise Physiology in order to screen for contra-indicators of exercise. Demographic information and anthropometrics of subjects were also taken. In addition, subjects were asked to fill out a mental toughness questionnaire developed by Loehr (1986).

The testing required three separate commitments, one day for the above information plus the 20 m shuttle run, one four hour period to test Pack C and another four hour period to test Pack D. All testing periods were separated by at least 48 hours.

3.2 Maximal Aerobic Fitness Test

The 20 M Shuttle run is an aerobic fitness test developed by Leger (1980) where there is correlation to maximal aerobic exercise on a treadmill ($r = 0.96$, $\Delta = 0.094 \pm 2.90$ ml O_2/kg/min, $S_{yx} = 2.81$ ml O_2/kg/min). A 20 meter distance is marked off with additional markers placed 2 m before the end of the shuttle run path. Subjects are asked to keep pace with a beep sound that signals ever increasing workloads after the subject has traversed 80 m (4* 20 m). The subject must keep pace with the beep and is allowed to fall slightly behind only once, based on not reaching the warning marker before the next beep. Two consecutive times of not reaching the warning marker constitutes a maximal score. This score is translated using the number of shuttles travelled, body mass and maximal heart rate into an aerobic capacity measure.

The beep test was administered to Queen's students in the Physical Education Centre and to the military reserves at the Armoury in Belleville. An experienced certified fitness appraiser worked with individualized research assistants for each subject. Three subjects were administered the test at the same time. Before the test, each subject warmed up and was fitted with a heart rate monitor around the chest that sent telemetric signals to a wristwatch. The research assistants identified when a person had failed the criteria and immediately read the maximal heart rate value. Water was given and a cool down period was also monitored. In addition and on a separate day, subjects took their resting heart rate while lying in a supine position.

3.3 Subject Preparations for the Circuit

Only one subject was tested at a time in the Physical Education Centre and duration of each test required four hours. Both students and soldiers wore military fatigues and a helmet with students wearing gym shoes and soldiers wearing combat boots. Subjects were given a second briefing and reminded that they could withdraw without coercion or penalty at any time. Then they were taught and walked through the circuit as part of the preparation and warm-up for the sessions respectively.

Each subject was fitted with a heart rate monitor that could be read from the wrist. Then a triaxial accelerometer was mounted onto the manubrium of the sternum with +(x,y,z) in the vertical plane. Cramer's quick-drying tape adherent (QDA) along with athletic tape was used to hold the sensor in place. This accelerometer was placed to capture the movements of the person during the circuit. The cable was run out the back neck of the shirt to the backpack. The first test of each session was Battle Order and no accelerometer was placed in the daypack.

3.3.1 Battle Order

The Battle Order trial was used as the baseline for that day of tests. Subjects donned a Tactical Assault Vest (TAV) that was filled with four C7 magazine cartridges, and two fake grenades, which weighed 2.73 kg. Then, subjects donned a CTS daypack that was filled with tennis balls and Styrofoam balls until it weighed 2.73 kg. Each subject also carried a replica of a C7 rifle during all tests. The total load was 5.45 kg, the equivalent typical Battle Order payload. Subjects were asked to select the maximum possible pace that they could sustain all day long. Subjects' heart rates were taken at the start line and time and heart rates were recorded after each station and after each marching phase. Once the timed circuit was complete, subjects answered a series of questions about each task in their data book before completing the wall touch task, posture task and a series of final questions. Each person was required to wear the Battle Order load for 20 minutes, which included the time needed to answer the subjective questions. Two video cameras with gym coverage were used to record each trial.

3.3.2 Marching Orders at Set Payloads.

Upon completion of all aspects of the Battle Order trial, the subject was outfitted with either Pack C or D. Both the order of the pack to be tested on the first or second day and the payloads of 10kg, 20kg and 30kg were randomized. A second accelerometer was mounted with screws onto the frame sheet and covered with a hard plastic cup as protection from the payload. The pack had small bags of tennis and Styrofoam balls on the bottom of the pack. Then, depending on the load to be carried, Universal Machine weights of 4.5 kg (10 lbs), anchored to a wooden plywood frame, were added into the pack. Next, more tennis and Styrofoam balls were added to distribute and occupy the volume. Lastly, a portable measurement system weighing 1.4 kg was place in the top of the pack.

Figure 3.1 Adjusting the pack for a subject

The subject then donned the pack without the TAV or daypack. A research assistant helped to adjust the pack to their personal preference. In-line strap sensors, accurate to r = .98 with force, were placed in the waist belt and lower shoulder (T2) strap. These two strap sensors, the on-body accelerometer and pack accelerometer were fed into an Embla® portable system (8 channels). The portable measurement system was pre-programmed to record data continuously at 50 Hz for a duration of 4 hours.

Subjects were asked to select the maximum possible pace that they could sustain all day long. Subjects' heart rates were taken at the start line with heart rates and time recorded after each station and after each marching phase. Once the timed circuit was complete, subjects answered a series of questions about each task in their data book before completing the wall touch task, posture task and a series of final questions. After the timed circuit component, soldiers completed questionnaires that deal specifically with balance, mobility and agility. The subject then completed the wall touch station and answered additional questions including identifying and rating areas of body discomfort as well as rating the LC System for load control and manoeuvrability during their circuit. Two video cameras with gym coverage were used to record each trial as a backup to viewing movements.

Each person wore each pack with its set payload load for 20 minutes. Upon completion of the session the subject was asked to rest and take refreshments for the remainder of the hour.

3.3.3 Self-Selected Payload

The final testing procedure in each pack was the *self-selected* load. Using the standard psychophysical protocol (Snook, 1978, Snook and Cirello, 1991; Ayoub, 1979; Mital, 1984) under the same task conditions, soldiers were asked to state the maximal load they would feel comfortable in carrying if they had to carry it all day long. Research Assistants loaded the pack with their requested weight and asked the subject to try it to see if it was correct. If necessary, the weight was adjusted as per subject selection. All other procedures were similar to the set load conditions. After soldiers have completed the self-selected circuit and reported their findings, the pack was weighed to determine the load each soldier had selected.

On the final day after all tests are complete, soldiers will be given a summary questionnaire where they will be asked to make comparisons across the two packs (C and D) stating reasons for their preferences.

3.4 Design of Standardized Load Control Circuit

A load control circuit was designed to fit into a small gymnasium in a space of 25 m by 15 m. The task items for the circuit were based on typical obstacles that one may encounter during Marching Order, such as: marching over even terrain with no obstacles, balancing on logs, boulder hopping, stepping over logs and under branches, climbing over fences, zigzagging through trees and walking up and down hills and on inclined hills. Table 1 summarizes the tasks and required subject load control responses.

Similar tasks to this standardized circuit were used in 1995 and 1997 while testing 24 and 28 soldiers respectively. Correlational analysis had shown the importance of these items in allowing soldiers to discern pack differences in load control, load transfer and subjective discomfort scores (Bryant et al., 1997; Doan et al., 1998). Soldiers' responses were correlated to a number of objective measurements on a Load Carriage Simulator and LC Compliance Tester. No one had ever hurt themselves on this circuit.

Table 3.1 Tasks and Load Control Characteristics need for balance and mobility

Station and Tasks	Required Human Load Control Characteristics
1. Straight Balance Boulder Hop	Side to side dynamic balance Front and back dynamic balance
2. Over logs	Lateral load control and dynamic balance
Under Branches	Forward load control and balance
Fence Climb	Torsional and forward load control and balance
3. Shuttle Walk	Horizontal travel load control and balance
Up/Down Ramp	Anterior posterior load control and balance
4. Sidewalk Ramp	Lateral load control and balance
5. Wall Touch Test	Suspension system flexibility & complex load control

3.5 Description of Tasks in Circuit

3.5.1 Marching with Load

The marching component involved two trips around the gymnasium. This component was used to separate the tasks and to create a more realistic Marching Order situation. The boundaries of the gym were clearly marked so that each subject travelled the same distance.

Figure 3.2 Marching for two laps of Gym

3.5.2 Station #1 Balance Beam and Boulder Hop

The balance beam was 14.75 meters long with a width of 9 cm. Subjects travelled between two cones to enter the straight balance task. The subject traversed the beam without falling off at a self-selected speed. There was a cone at the end of the circuit to be sure all have traversed the same distances. All subjects completed the task twice in sequence with the boulder hop.

There were 13 boulders, each one being 30 cm in diameter of plastic non-clip coloured discs. The 'boulders' were 1.5 m apart from each other (centre to centre) and at 110º angles from each other. After going around an end cone from the balance beam, subjects had to move from one boulder to another, placing both feet on each boulder. Subjects completed the boulder hop twice, then went through the timing gate and reported their Station #1 final heart rate.

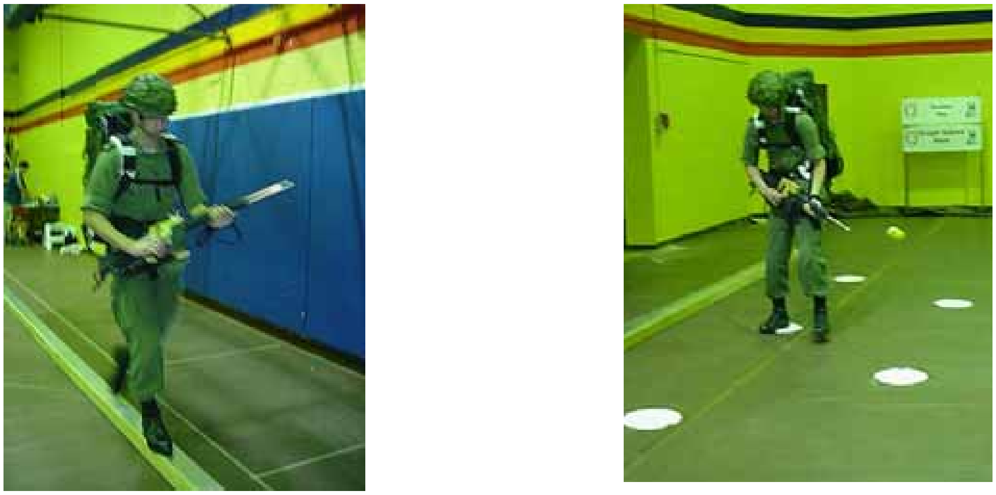

Figure 3.3 Station #1 : Straight Balance beam and Boulder Hop

3.5.2.1 Logs, Branches and Fences

Station #2 is a combination of tasks covering a 20 m distance. There were three logs 20 cm in diameter and 50 cm above the floor. These logs were constructed of framing lumber and Sona tubes (Figure 3.3 a). These logs were interspersed with branches of 1.5 m from the ground that forced the subjects to duck or shuttle under them. The branches were made of framing lumber and held secure with sandbags on floor angle braces. The distance between each branch and log was 2.6 m.

Figure 3.3a Station #2 consisted of alternating logs and branches followed by fence climb

The last aspect of this Station #2 was a fence climb where the subject had to scale the 1.2 m high fence after the log-branch phase. The subject would then travel around a marker cone and return to the start line over the same fence. This task was completed two times. At the end of two repetitions of station #2, the subject went through the timing gate and reported his final heart rate. This was followed by two laps around the gym.

Figure 3.3b The Fence Climb

3.5.2.2 Shuttle Walk and Up/Down Ramp

The subject walked through a timing gait and zigzagged through a shuttle course of pylons that was 19.35 m long. Each pylon was 2.15 meters apart and at an angle of 135º. The subject then journeyed around an end marker and marched up a ramp that was 4.5m long and at an angle of 21º. The subject exited via the downward ramp of the same dimensions, walked around an end cone and repeated the circuit twice. After the second repetition, the subject traversed a timing gait, reported his heart rate and walked two times around the gym.

Figure 3.4a The Shuttle Walk

Figure 3.4b The Up and Down Ramp, which had a non-skid surface on it

3.5.3 The Side Hill Ramp

The side ramp was 7.5 m long and at an angle of 26º. The subject would walk through a starting gait and walk up onto the slant at one end, traverse the slope and exit at the other end. He would walk around a marker cone and then return the same way. This task was repeated twice after which the subject went through the timing gate and reported his final heart rate. This was followed by two laps around the gym.

Figure 3.5 The Side Slant Ramp

3.5.4 Wall Touch Test

A frame was built with framing lumber that was 3 m high and 2 m wide. On it, target switches were placed on both sides at 50 cm and 175 cm above the floor. The task was to touch as many buttons as possible in 30 seconds first with the right hand. The subject started with the lower right switch and followed the pattern in Figure 3.6a. This was repeated for the left hand for 30 seconds also. The score was how many touches in the time period. Heart rate was taken after each hand.

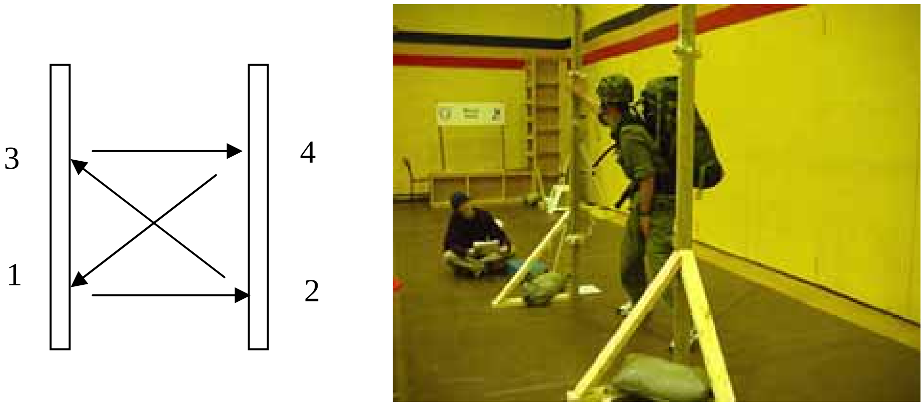

Figure 3.6 a) The subject touched each button in the sequence and b) used only one hand at a time

3.5.5 Posture Task

After the final questionnaire on previous circuit perceptions, a standing photograph was taken from a side view. In this photograph, the subjects aligned with themselves even with a conversion ruler (Figure 3.7). Within the view was also an identifier for the subject as well as a load mass indicator. They were asked to look straight ahead in a natural stance for that load. This photograph was used to determine postural adjustments to pack load and shoulder and lumbar reaction forces based on pack weight and design.

Figure 3.7 Standing posture with load

3.6 Data Acquisition During Circuit

After subjects were outfitted for their trial (Battle Order, light, medium, heavy loads and self-select), they came to the start line. A research assistant read the following instructions: *“ You are asked to self-select the fastest pace possible assuming that you will be marching all day long with this weight. Do not run. You will wear the pack for 20 minutes. Self-select your fastest pace that is possible for you to sustain all day long.”*

Subjects then read off their initial heart rate to the recorder and started around the initial two laps. Heart rates were reported at the end of laps and after each station. Split times were also taken. Once they had completed the timed component of the circuit, they filled out specific questions about each task in terms of balance, mobility, agility and control. Then, subjects posed for a postural photograph from the side. Subjects then completed the timed wall touch task and answered questions about this task. Finally, they were asked to complete a discomfort and pain diagram and general acceptability of the load and pack. The rest period between packs was approximately 30 minutes. After the last day of testing, subjects were asked questions to compare between packs. Addendum A is a complete subject data booklet.

3.7 Data Analysis and Management

The data from each subject's book was recorded in Excel spread sheets. One Excel workbook called "Marching Order data books" was used to hold all of the numeric data from the data books. Descriptive data and graphs were also developed in this Excel workbook. These data were transferred to SPSS for statistical analyses using two way and three way repeated measures ANOVA subroutines.

Data from the mental toughness questionnaire were retained in an Excel spreadsheet called "performance inventory". Psychological profiles were developed related to performance and graphed in Excel as well.

Data from the standing posture with the backpacks were digitized using the program "dig". Landmarks for the backpack straps angles, pack and person centres of gravity were digitized on each photograph and submitted to an Excel spreadsheet called "Biomechanical Model-Static" for analysis. The shoulder based Phase I model developed by MacNeil (1996) and reported by (Stevenson et al, 1995; 1996) was used for the Battle Order and the Phase II model developed by Pelot et al (1998) was used for the Marching Order trials. The main variables that were extracted were: body lean angles, shoulder and lumbar reaction forces, and ratios of load on shoulder and lumbar regions. Descriptive data and graphs were also developed in this Excel workbook. These data were transferred to SPSS for statistical analyses using two way repeated measures ANOVA subroutines.

Data from the self-selected trial were stored in the Excel workbook called "Marching Order data books". These data were combined with the motivational inventory to determine whether motivation or personal fitness levels were related to choice of self-selected load. Descriptive data and graphs were also developed in this Excel workbook.

Finally, subjective feedback on discomfort and pain and overall summary of pack preference were analyzed quantitatively and qualitatively. From these subjective responses, arguments were made to explain the preferences given by soldiers.

4. Results and Discussion

4.1 Subject Characteristics

In total 13 subjects, eight soldiers and five students volunteered for the study. Some subjects were eliminated from the pack testing phase either because of fitness level or small size. This was necessary as we did not want poor fitness levels to affect the data and we only had one large Pack D for testing. In terms of anthropometry and demographics, there were no significant differences between the samples using a two tailed paired Student's t-test (Table 4.1).

Table 4.1 Demographics and anthropometrics of student and military subjects

Variables	Units	Soldiers		Students		Combined	
		Mean	**S. D.**	**Mean**	**S. D.**	**Mean**	**S. D.**
Number of Subjects	#	8		5		13	
Age	Years	20.63	2.67	22.60	2.51	21.38	2.69
Standing Height	cm	175.97	5.58	177.61	3.42	176.60	4.77
Weight	kg	74.56	6.58	75.98	6.08	75.10	6.17
Neck Circum	cm	37.38	1.94	37.63	1.25	37.46	1.68
Chest Circum	cm	92.71	4.91	93.13	5.04	92.86	4.62
Waist Circum	cm	81.13	4.71	81.38	1.82	81.21	3.93
Buttock Circum	cm	100.38	4.98	98.88	3.22	99.88	4.41
Biacromial Breadth	cm	45.88	1.75	46.25	6.85	46.00	3.84
Waist-Back Length	cm	49.63	4.73	50.75	0.89	50.00	3.85

Both students and reservists completed the 20 m shuttle run test, which elicits a maximal heart rate and is predictive of maximum oxygen consumption (Leger et al., 1980). This prediction during the circuit was done with the formula:

$$\text{Predicted } \%MVO_2 = (\text{exerciseHR} - \text{restHR}) / (\text{maximumHR} - \text{restHR}) * 100$$

Therefore, using the subjects' heart rates during testing, the percentage of their MVO_2 at which they are working can be predicted without having to directly measure oxygen uptake under testing conditions.

There were no significant differences in resting or maximal heart rates. However, there was a significant difference ($F=38.0$; $p=0.001$; $df=1$) in the aerobic capacity measures since the students covered a greater number of laps during the maximal aerobic test. In other words, all students were more physically fit than their military counterparts (Table 4.2).

Table 4.2 Maximal heart rates and maximal aerobic fitness of subjects

Variables		Soldiers		Students		Combined	
	Units	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Resting Heart Rate	beats/min	64.6	6.7	59.4	3.7	62.6	6.2
Maximal Heart Rate	beats/min	204.6	5.6	200.2	5.9	202.9	56.8
Max. O2 Consumption	ml/kg/min	43.9*	3.8	55.0*	4.0	48.2	6.7

* significant at p=0.001

4.2 Relationship between Subjects at Various Loads

In circuit testing, each subject wore Battle Order at 5.5 kg. This was used as a baseline for aerobic demand. Then each subject carried randomized loads of 15.7 kg, 25.5 kg and 34.4 kg (followed by the self-selected load). Both the times of the circuits and the aerobic demands were compared between students and reserves using two-way repeated measures ANOVA. There were no significant differences for circuit times between reservist and students or between packs worn by students or between packs worn by reservists.

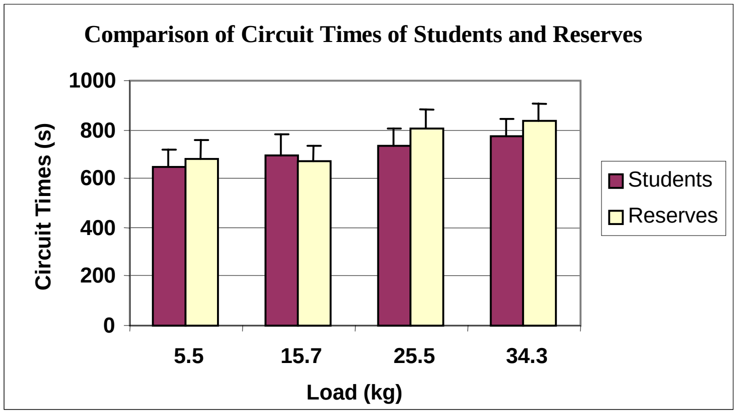

Figure 4.1 Students and Reservists had no significant difference in circuit times

A second comparison was performed between predicted oxygen consumption (VO_2) of percent maximal oxygen consumption between students and reserves across loads. There was a significant difference in VO_2 between students and reserves at each load mass (F=38; p=.001; df=1) (Figure 4.2). Reserves were working harder to accomplish the same times on the circuit. It is well known physiologically that if someone is less physically fit, it will require a greater metabolic demand to do the same amount of work such as working at the same pace. Hence we are looking at differences in fitness levels, not differences in self-selected paces to complete the circuit. Circuit times and aerobic demand differences were used to make the decision about whether we should separate reserves and students or pool them as subjects of varying fitness levels. Because circuit times did not differ significantly, subject data were pooled in subsequent comparisons.

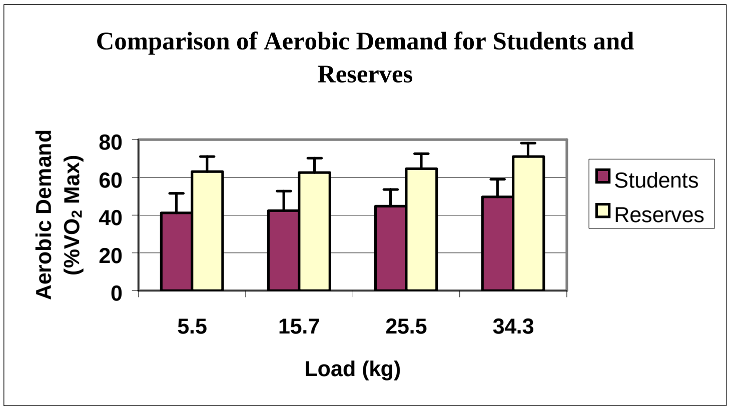

Figure 4.2 Predicted VO_2 levels were significantly different between groups

4.3 Relationship between Pack Type and Load

Each subject wore each pack for 20 minutes during Battle Order (5.45 kg), and pack conditions 57.7 kg, 25.5 kg and 34.3kg. Using a two–way ANOVA for repeated measures (pack and load) it was shown that there was no significant difference between packs C and D, However, there was a significant difference in the circuit time for each load (F=86.7, p=.001, df=3). There was no interaction effect between time and load.

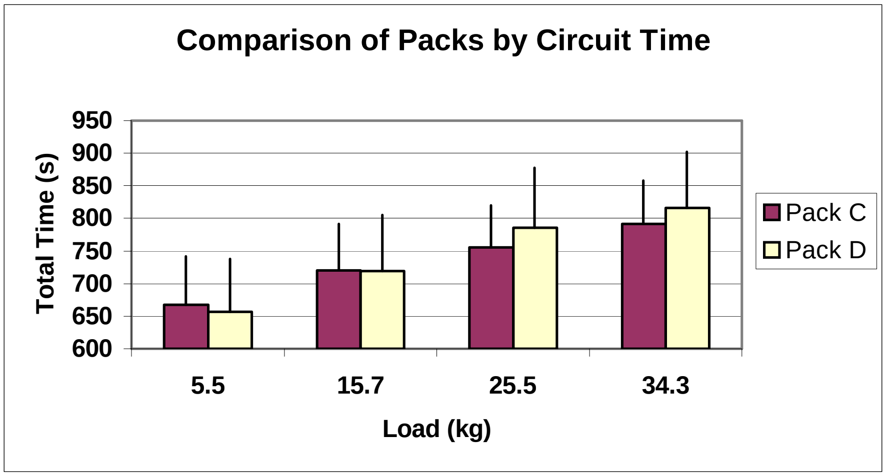

Figure 4.3 Total Time to complete circuit with Packs C and D by load

For aerobic demand, based on predicted percent of maximal aerobic capacity (%MVO_2), there was no significant difference by pack (Figure 4.4). There was a significant difference in aerobic demand based on load (F=20.8; p=.008, df=3) that was not group dependent (students, reserves). The only pairings where there were no significant differences in aerobic demands were between loads 5.5 kg and 15.7 kg. Otherwise, aerobic demand was increased with each load mass increase for subjects. These results are consistent with previous research, which states that during dynamic exercise at a constant speed oxygen uptake increases linearly with the amount of weight carried (Borghols et al. 1978, Patton et al. 1991).

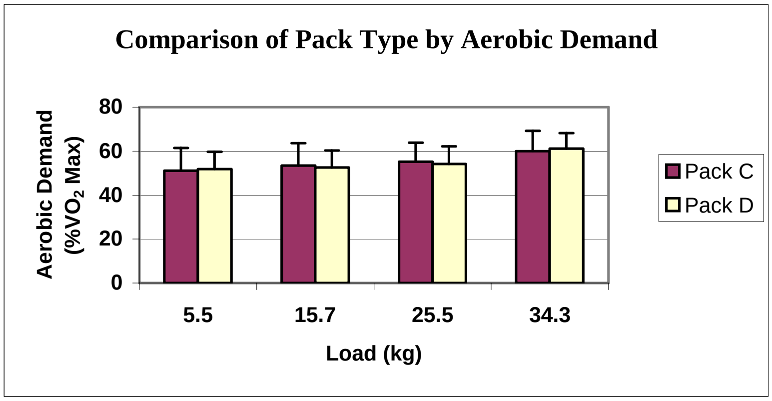

Figure 4.4 Percent of maximal oxygen consumption by load and by pack

4.4 Self-Selected Load

Each subject was asked to select the maximum weight they could carry comfortably all day long. Then, they were asked to select the maximum possible pace that they could sustain all day long. Subjects were asked to make their decision on load and check the load to confirm their choice before starting the circuit. The goal was to use the psychophysical approach, used by Snook and Cirello (1991) and Ayoub et al. (1989), to see what load and level of discomfort they were willing to accept all day long.

Results revealed that subjects selected an average load mass of 23.9 ±3.5 kg for Pack C and 22.8 ± 3.2 kg for Pack D. This was very close to the medium load that all subjects were asked to carry. There was no significant difference between what weight subjects chose for Pack C and Pack D. Subjects #5, 6 and 9 wore Pack C only and were not used in comparative statistics for other measures.

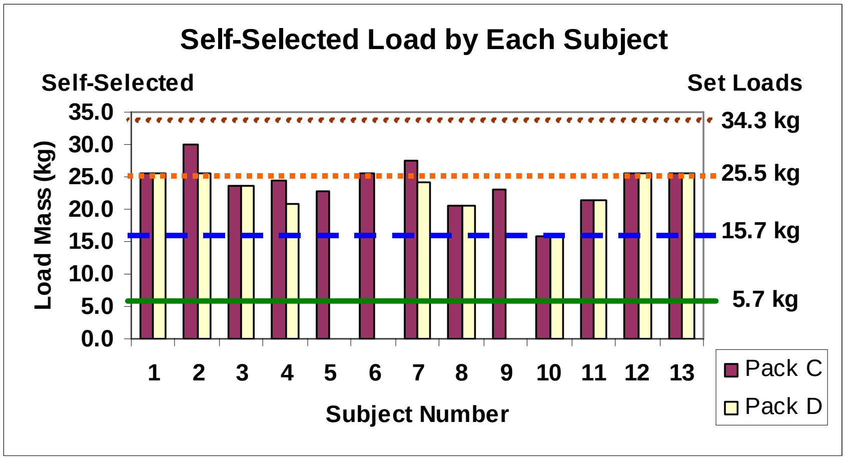

Figure 4.5 Individual loads that subjects chose to carry in Pack C and Pack D

Three possible explanatory factors were evaluated for the determination of self-selected load; aerobic capacity, body mass and motivation (Figure 4.6a,b,c). In all cases, these variables were not correlated to the self-selected load. Hence the relationship to choice is more complex than just these factors.

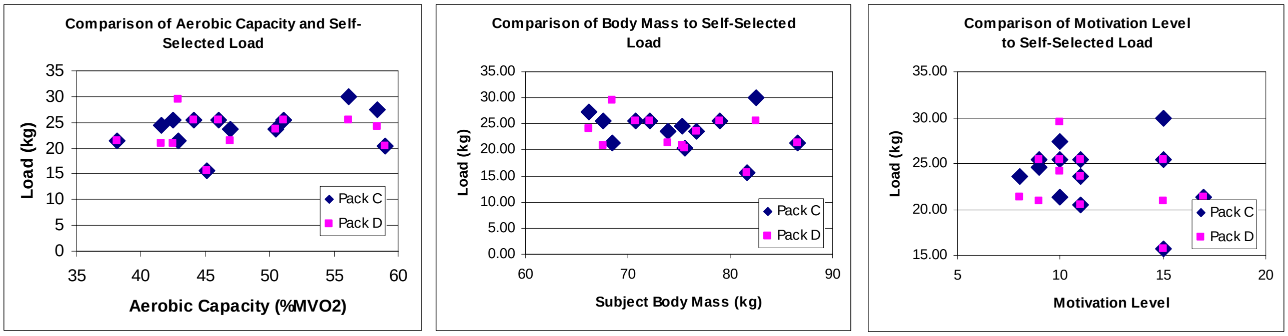

Figure 4.6 Self-Selected load in comparison to a) maximal aerobic capacity, b) body mass and c) motivational level

4.4.1 Self-Selected Load and Circuit Time

When the time taken for the circuit and the percent of maximal aerobic consumption was evaluated, the self-selected trial was relatively close to the required load of 25.5 kg (Figure 4.7). The self-select trial was always last, although the other trials were randomized. It is possible that fatigue had a bearing on the selection of weight to put into the pack.

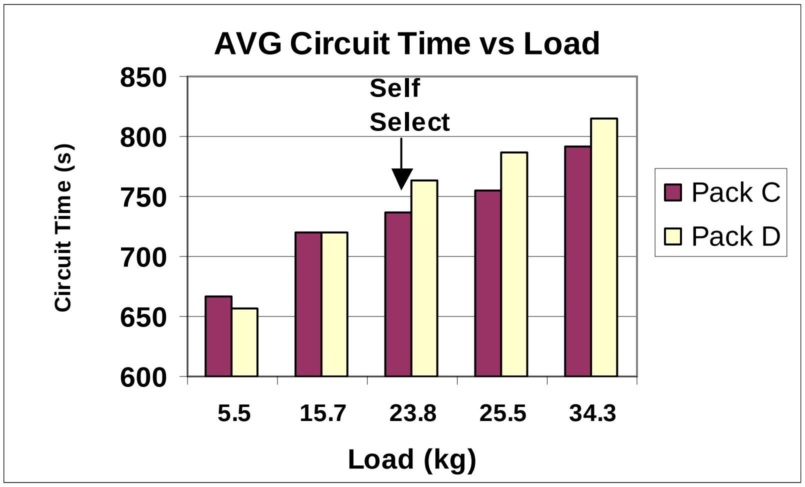

Figure 4.7 Self-Select circuit time in comparison to standardized loads

4.4.2 Self-Selected Load and Aerobic Capacity

The aerobic demand of the self-selected load was higher than the required 25.5 kg weight, opposite to the time of the circuit (Figure 4.8). These differences would suggest a trade-off between time taken and VO_2. This may also suggest fatigue.

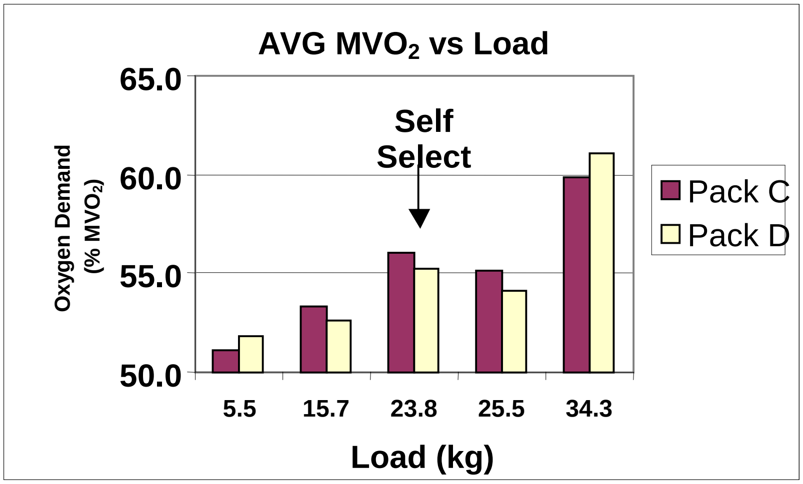

Figure 4.8 Self-Select aerobic demand in comparison to standardized loads

Earlier studies have shown that energy cost during prolonged load carriage is not constant but increases significantly over time, (Patton et al. 1991). This could explain the higher oxygen uptake value for the self-selected load when compared to standardized loads, considering this trial was consistently the last session performed. This gradual increase in VO_2 occurs under a variety of exercise conditions and potentially could be attributed to several factors, including an increased body temperature, increased V_E, increased blood lactate, a shift in substrate utilization, and a reduced mechanical efficiency, (Michael et al. 1961; Saltin and Stenberg 1964; Hagberg et al. 1978; Sawka et al. 1979; Casaburi et al. 1987; Kalis et al. 1988, Patton et al. 1991). Similarly, Patton et al. (1991) believe that this reduction in mechanical efficiency with prolonged load carriage may be of particular importance to the observed increase in VO_2 due to altered locomotion biomechanics as the subject adjusts to the weight of the pack.

Since subjects maintained a pace consistent with other load profiles, one would need further research to see if the load selected was in response to fatigue. Testing the self-selected load on a different day would help in understanding whether fatigue influenced the self-selected load condition.

4.5 Percent Drop-Off in Performance

To determine if circuit performance was negatively affected by load, the Battle Order trials were used as the baseline for each subject. Then the circuit times were expressed as a percentage drop-off in performance (based on an increase in circuit time). Figure 4.9 is a summary of total time and shows that as load increased, so did the time it took to complete the circuit. Using a two-way repeated measures ANOVA, there was not a significant difference in time by pack (F=4.42; p=0.069, df=1) but there was a significant difference in performance time by load (F=49.9; p=0.001; df=3). Pack D was physically higher on the body. This was a disadvantage when moving under barriers and controlling the load. It was an advantage, however, during marching as less of a body lean angle would be required.

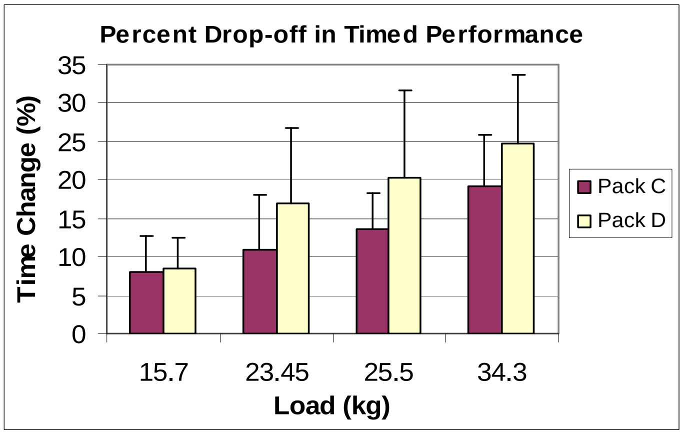

Figure 4.9 Circuit time increases by load and by pack

Figure 4.10 demonstrates the changes in aerobic demands when expressed as a proportion of Battle Order load. The graph shows more variability in aerobic capacity with increased load. Results of a two way repeated measures ANOVA comparing percentage change by pack and load reveals that there was no significant difference by pack, because of the large standard deviations but there was a significant difference by load (F=9.3; p=0.001; df=3). Hence, within subjects, the aerobic demands increased with load, but there was an interaction effect between load and pack.

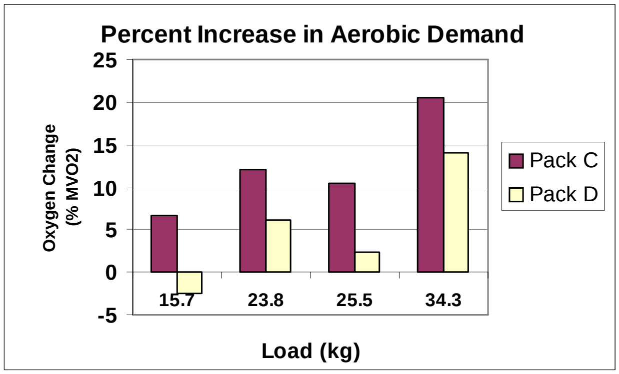

Figure 4.10 Aerobic Capacity increases with increased load by pack

To determine where subjects lost time, Figure 4.11 shows the lap and tasks times by pack. The decrement in performance ranged from 5% to 15% on average for laps. There was close to a significant difference between packs (F=4.67; p=0.059; df=1) and there was a significant difference between loads (F=7.45; p=.001; df=3) that occurred at all load weights.

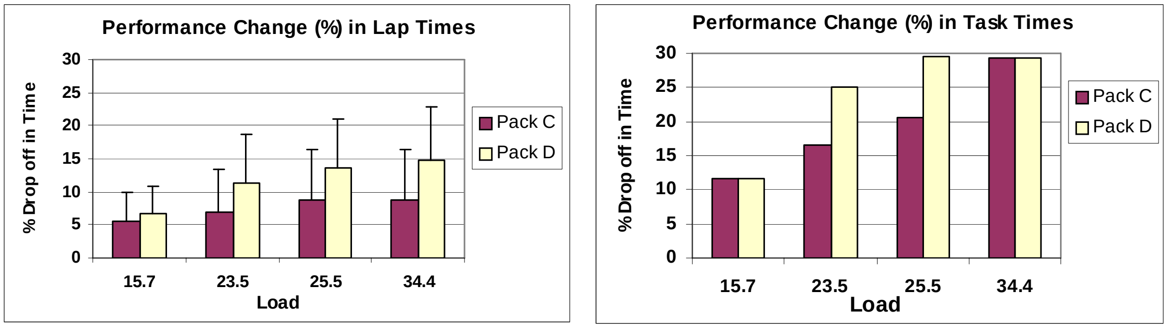

Figure 4.11 Percent drop-off in performance times during a) laps and b) tasks.

However, for tasks, the times were much poorer with load. Performance dropped from 11% to 29% on average. This was due to load (F=10.5; p=0.001; df=3) with significant differences between reach load weight. With the added load, subjects moved more slowly as they navigated the obstacles. Especially during task #2 the times were increased dramatically.

In Figure 4.12 the aerobic demands of tasks were assessed. For laps, aerobic demands were not significantly different between packs but were between loads (F=5.7; p=0.004; df=3). The oxygen demands ranged from 0% in comparison to Battle Order, up to 27%. The energy demands on Pack D were less than Pack C, perhaps because they moved more slowly through the circuit or because of the design.

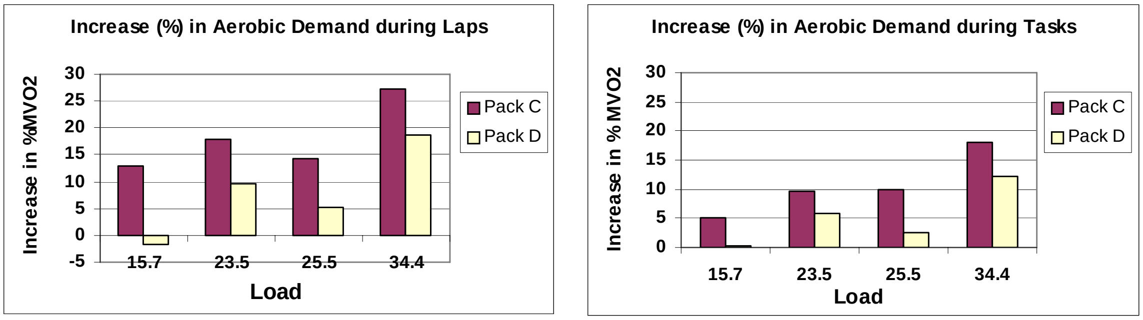

Figure 4.12 Percent drop-off in performance times during a) laps and b) tasks.

During the tasks (Figure 4.12b) the aerobic demands were lower than for laps, probably because of the delayed onset of aerobic and anaerobic demands on the system. There was no significant difference between packs but there was between loads (F=10.6; p=0.001; df=3). The energy demands ranged from 0% to 17.5% with both the 25.5 kg and self-select packs (23.5 kg) at 10% above Battle Order.

The percent decrement in performance did not appear to be related to pack type, although at times, the packs appeared different graphically. There was a very large standard deviation within subjects so graphs are misleading in showing pack differences.

When the raw data were examined, interesting strategies were employed for Pack C (Figure 4.13). Except for the heaviest load, 7/10 subjects kept the aerobic capacity almost constant by increasing the time to complete the circuit. However, 3/10 subjects allowed their MVO_2 to climb dramatically. These three subjects wore Pack C first and may not have appraised their capacity properly. It would appear that the preferred approach is to move more slowly and prevent the aerobic demands from rising too high.

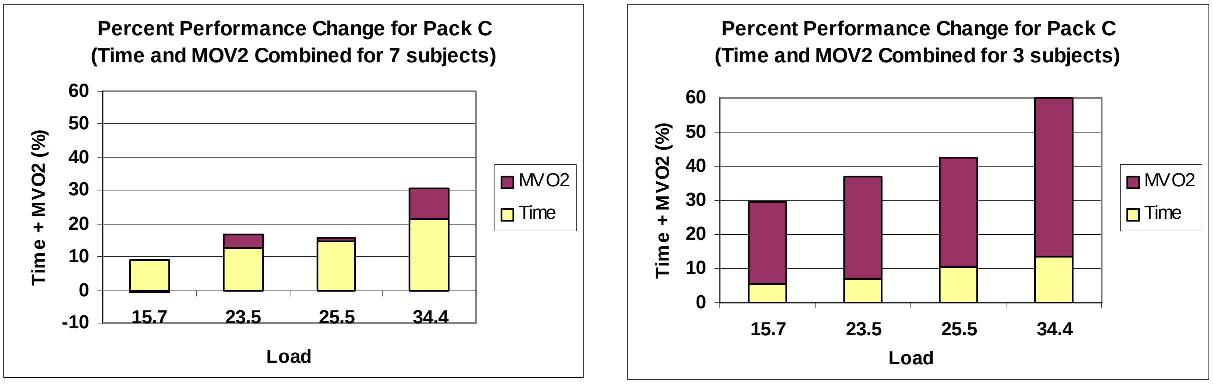

Figure 4.13 Pattern of Performance drop-off for Pack C: a) 7 subjects and b) 3 subjects.

For Pack D only one subject had high MVO_2 values and also wore Pack D first. Figure 4.14 is the average of 9/10 subjects. The pattern of adjustment to load seems to be the same as with the majority of subjects with Pack C. Subjects tended to slow down during the circuit, and it wasn't until 34.3 kg packs that the energy demands rose substantially. It would appear that this is the control mechanism most soldiers use when moving through mixed terrain with heavy backpacks.

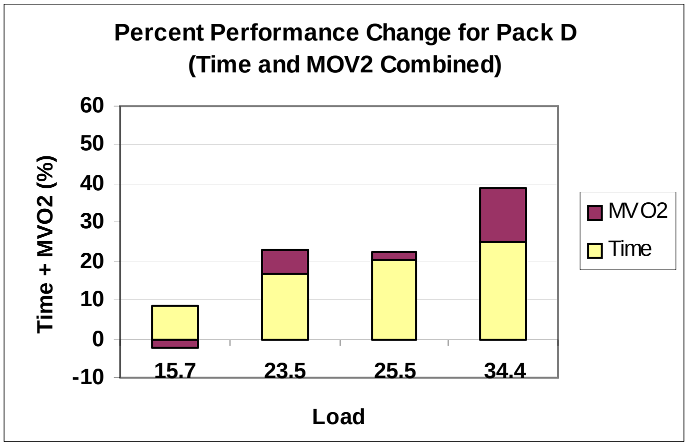

Figure 4.14 Pattern of Performance drop-off for Pack D for 9/10 subjects.

Occasionally the self-selected load trial (~23.5 kg) had slightly higher demands than the 25.5 kg trial. Considering the self-selected load trial was performed consistently last, it is possible that the subjects were fatigued as a result of previous tasks and sessions. This fatigue would have caused them to work at a higher percentage of their VO_2 max in comparison to earlier trails with standardized loads.

4.6 Detailed Circuit Analysis

4.6.1 Time For Laps within Circuit

Detailed analysis was conducted to determine where the subjects lost time during their performance. Figure 4.11 and 4.12 display the time taken, in seconds, for pairs of laps at the beginning of the circuit and after every task for Pack C and Pack D respectively. A three way repeated measures ANOVA using within factors or pack, load and laps times was conducted. The only tasks that were not randomized were the Battle Order baseline at the beginning and the self-selected task at the end of the testing period.

There is a significant increase in time taken for each added load (F=23.3; p=0.001; df=4). This would indicate that their overall walking cadence was reduced with each increased load. However, there is no significant decrement in performance within a load condition. This indicates that the subjects were not changing their lap speeds during a given load. However, they were slowing down with increased load.

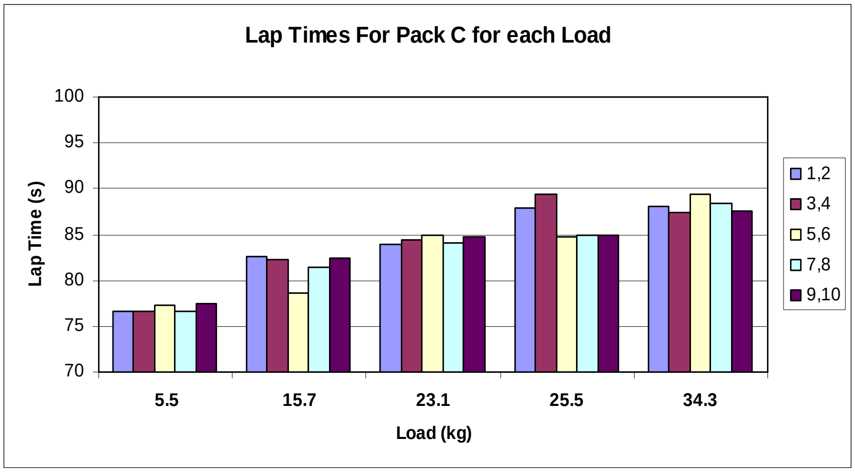

Figure 4.15 Comparison of lap times by load for Pack C

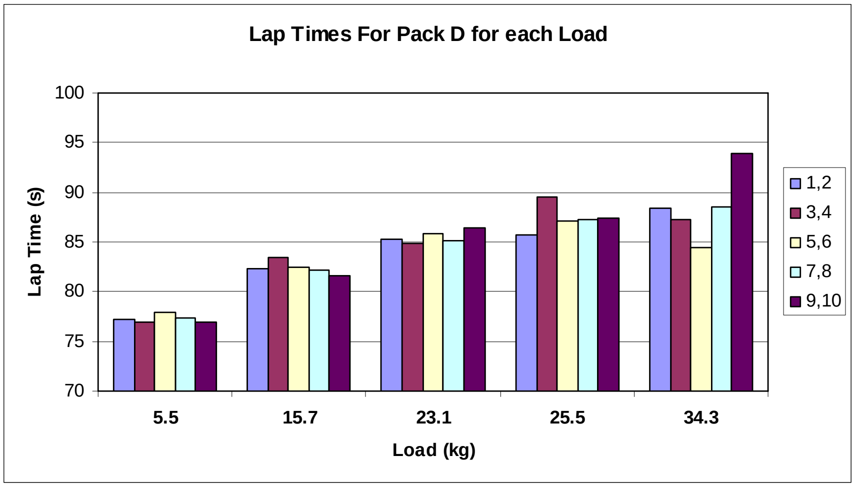

Figure 4.16 Comparison of lap times by load for Pack D

4.7 Aerobic Demand of Laps within the Circuit

Figure 4.17 and Figure 4.18 represent the percent of maximal aerobic capacity that is exhibited during the lap component of the circuit for Pack C and Pack D respectively. Using a three way repeated measures ANOVA with packs, loads and laps, there was no significant difference between packs. There was a significant difference between loads (F=13.0, p=0.001; df=4) and between laps (F=24.5; p=0.001, df=4) as well as an interaction effect between loads and laps (F=2.42; p=0.004; df=16). Using a series of planned comparisons, the main differences occurred between the 15.5 kg and self-selected load and between the 25.5 kg and 34.3 kg loads. The aerobic demand rose after the boulder hop tasks (laps 1,2) and especially after the over/under/fence task (laps 3,4). After Station #2, the over, under and fence climb, aerobic demands rose from 50% to 70% maximal capacity over the five load conditions. The heart rates have probably not recovered from these stations. The last two tasks were not as demanding, leading to a lower overall decline in demand during the last two sets of laps.

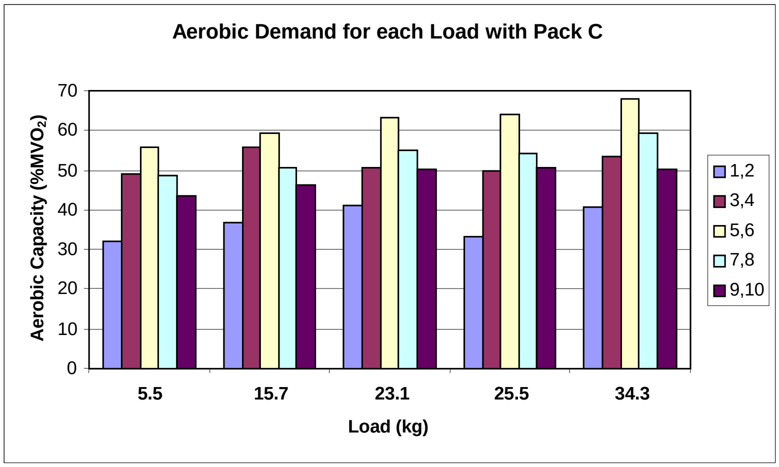

Figure 4.17 The %MVO$_2$ during laps between tasks for Pack C

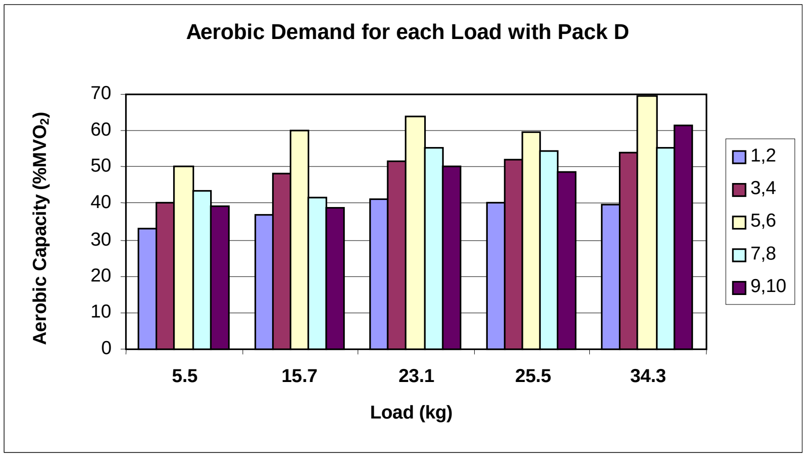

Figure 4.18 The %MVO_2 during laps between tasks for Pack D

4.7.1 Task Times by Load within the Circuit

Subjects completed the circuit five times with fixed weights in randomized order. Figure 4.19 and 4.20 reveal where subjects lost time during the circuit tasks (wall touch is counted on number of touches made). Using a three way ANOVA for repeated measures, there was a decrease in performance time for each task with load (F=37.0, p=0.001, df=4) but not between packs (p=0.144). The most observable task with a drop-off in performance was the over/under fence task (#2). This task required the subject to travel under a 1.5m high bar where subjects either kneeled or ducked, placing the pack in a horizontal position. There was significant interaction between packs and stations (F=2.9, p=0.055, df=3) due primarily to difference between for the balance/ boulder hop station and the over/under/ fence station. This could be due to Pack D's higher height and less lateral stability because of its design.

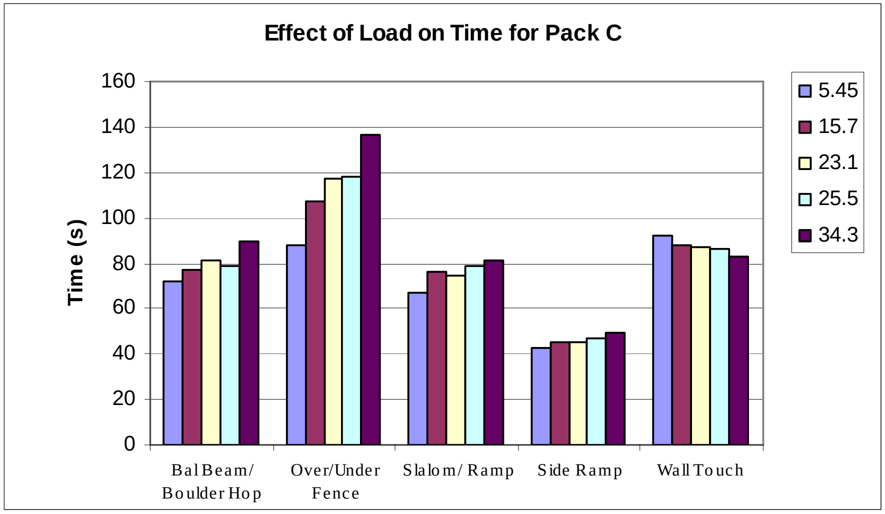

Figure 4.19 Effect of load on task time in circuit for Pack C

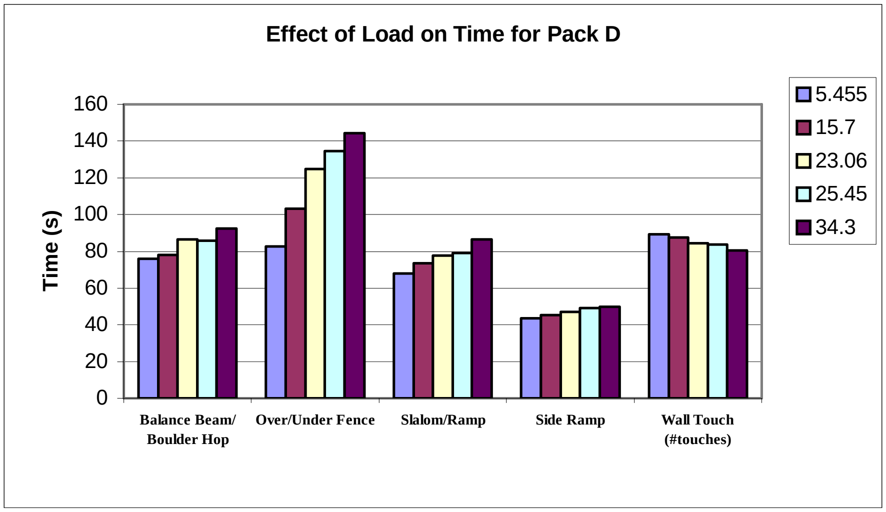

Figure 4.20 Effect of load on task time in circuit for Pack D

4.7.2 Comparison of Aerobic Capacity by Pack during Tasks

Based on a three way repeated measures ANOVA, there was no significant difference between packs but there was a significant difference between loads (F=12.9, p=0.001, df=4) and between MVO_2 for each task (F=28.3, p=0.001, df=3). There is also a significant load-MVO_2 interaction (F=3.1, p=0.001, df=12). This interaction was a result of the differing aerobic demands per tasks in that longer task times resulted in higher %MVO_2 (Figures 4.21 and 4.22). The aerobic demands after tasks ranged from 50% to 80% MVO_2 for Pack C and from 51% to 78% for Pack D. Demands were highest for Task #2, the over/under/fence task, which required the most extreme postures and longest task times. The aerobic demands during the lap following this task were also higher than other tasks due to recovery from the task demand (see Figures 4.17 and 4.18).

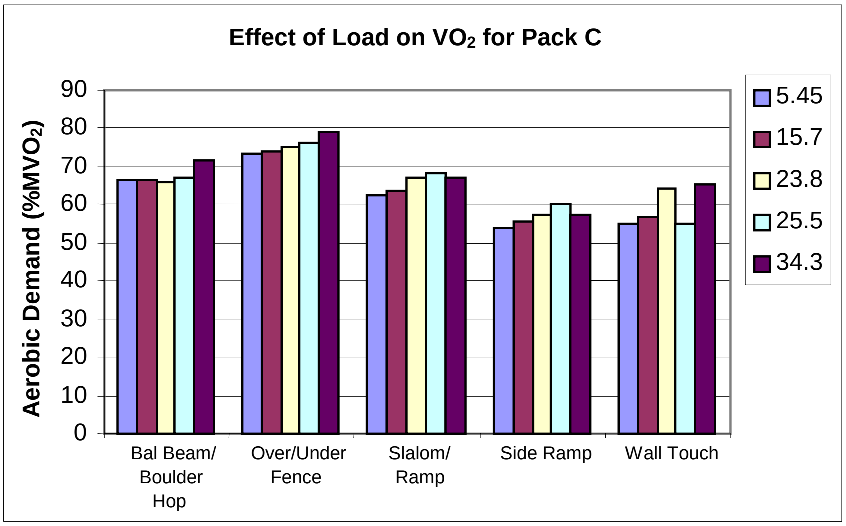

Figure 4.21 View of aerobic capacity across all tasks for all loads with Pack C.

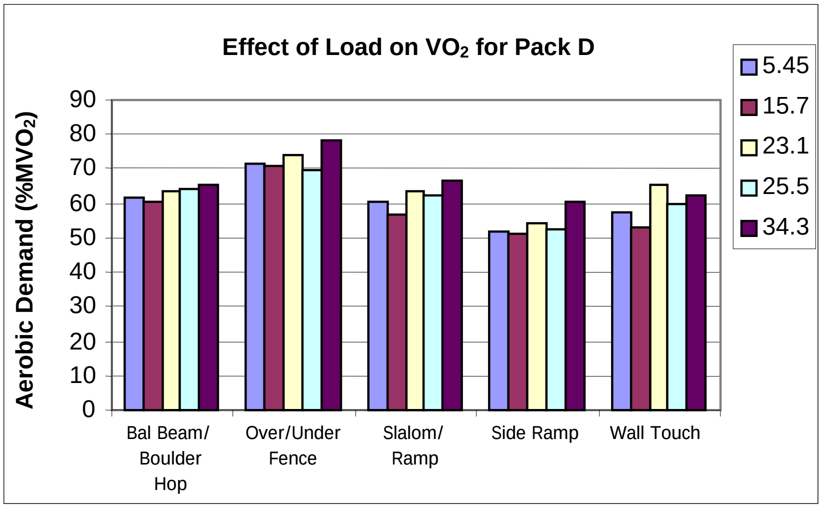

Figure 4.22 View of aerobic capacity across all tasks for all loads with Pack D.

4.8 Percent Change in Performance during the Circuit

4.8.1 Percent Increase in Time of Circuit

One of the measures used to evaluate performance is the change in performance expressed as a percent drop-off from Battle Order conditions. By understanding the main factors that affect performance and subjects' response to these factors, we hope to better understand factors that will limit load carriage capacity.

Within the circuit, there was a 5% to 15% drop-off in time during the laps in comparison to Battle Order. This was approaching significance by pack (F=4.67; p=0.059; df=1) and significant by load (F=13.4; p=0.005; df=3). This pattern was also true for task times where the drop-off in performance was 11.6 % to 29.2 % for 15.5 kg to 34.3 kg respectively. There was no significant difference between packs but there was a difference between loads (F=27.6; p=0.001;df=3). In other words, the additional time was absorbed in both walking and load control tasks with the tasks requiring the far greater increase in time.

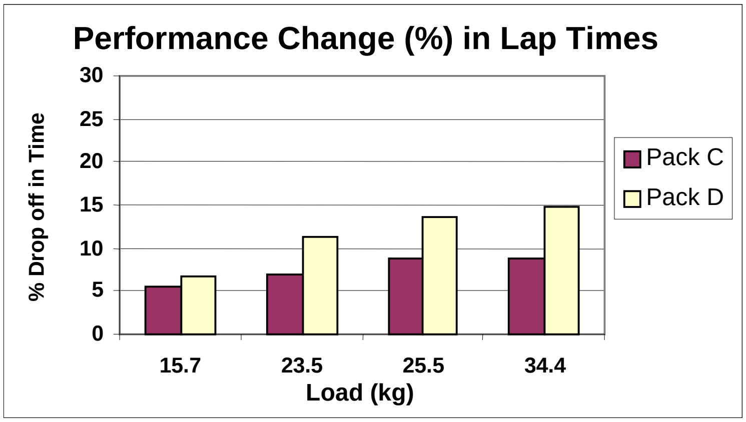

Figure 4.23 Percent decline in performance for lap times

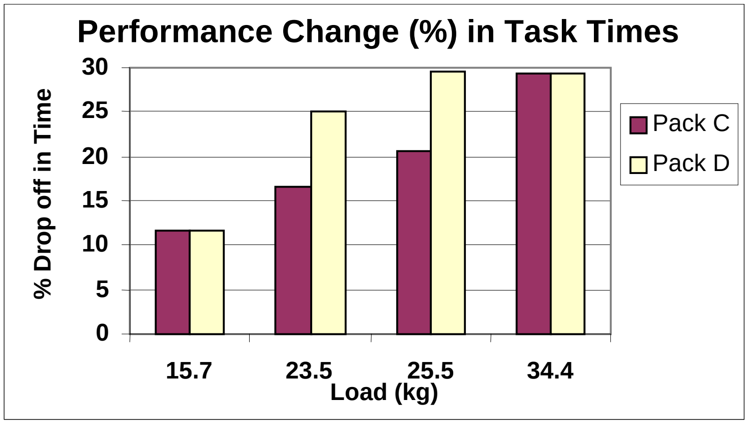

Figure 4.24 Percent decline in performance for task times

4.8.2 Percent Increase in Aerobic Demand based on Circuit

Figure 4.25 and 4.26 show the increase in aerobic demand during laps and tasks respectively. The subjects' aerobic responses were more dramatic than the increase in time taken for the circuit. During the laps, there was no significant difference between packs and load (F=4.7; p=0.062; df=3). During the tasks, again there was no significant difference by pack but there was a significant difference by load (F=16.0; p=0.004; df=3). During the laps, aerobic demand increased by 27.1% during the 34.4 kg load. For the intermediate loads, the increases were around 15% of Battle Order. For the tasks, only the 34.4 kg load caused greater than 15% increase in aerobic demand from the Battle Order baseline.

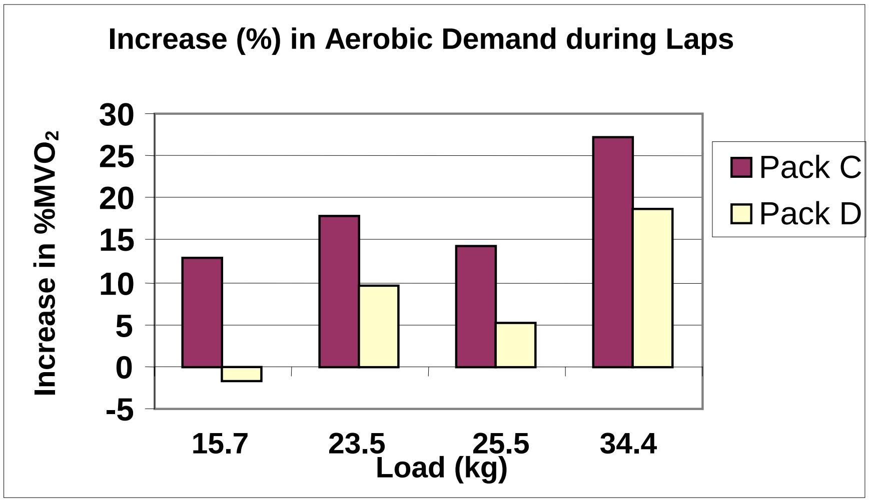

Figure 4.25 Percent increase in aerobic demand during laps

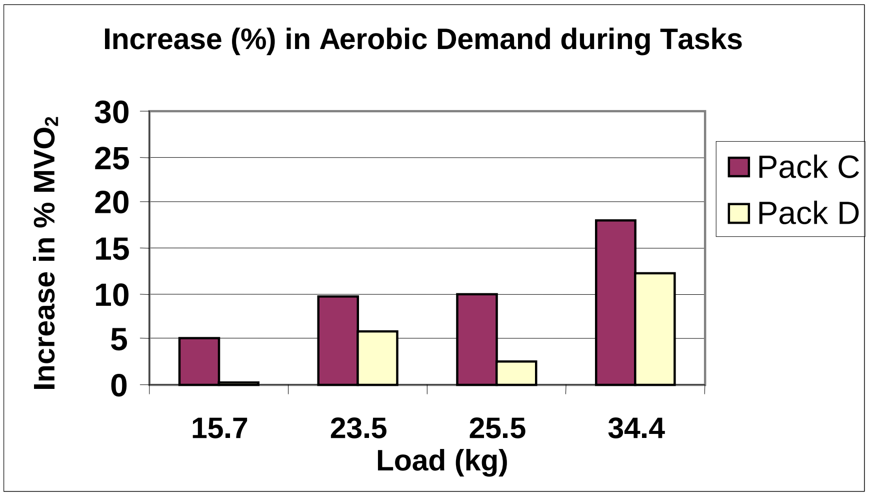

Figure 4.26 Percent increase in aerobic demand during tasks

4.9 Summary Subjective Responses to Circuit Demands

Figure 4.27 is the summed responses of all subjective responses to all questions based on load. Subjects were asked to rate and explain the demands of the tasks on a six-point scale with the following identifiers:

6	Totally Acceptable
5	Quite Acceptable
4	Somewhat Acceptable
3	Somewhat Unacceptable
2	Quite Unacceptable
1	Totally Unacceptable

Two way repeated measures ANOVA using within factors of packs and loads was conducted at two levels: 1) as an overview of all summed responses to questions within the circuit; and 2) individual responses to each question. The wall touch responses were also added to create an overall response by pack and load.

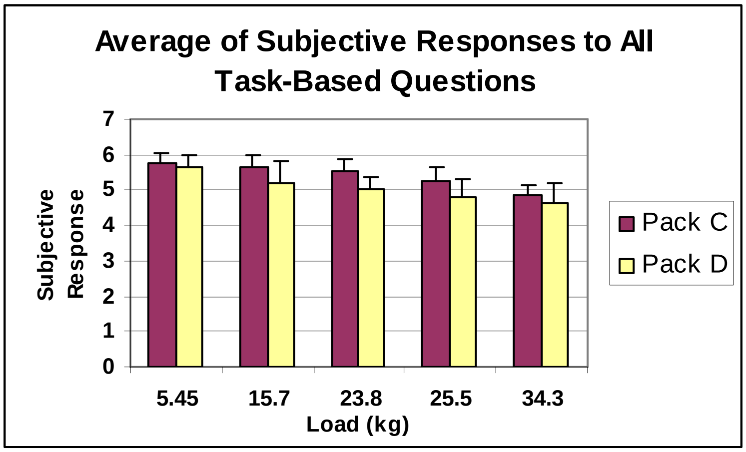

Figure 4.27 Summary graph of summed responses to all questions

The purpose of an overall response score is to get a general sense of subjects' perception of the pack for comfort, stability, mobility and balance across each pack for a number of tasks. The answer to each question was added and weighted equally in terms of an overall response about the pack and the load conditions. A two way repeated measures ANOVA for pack and load was used to examine each question. There was a significant difference between packs (F=2.9; p=0.005; df=1) as well as a significant difference between loads (F=16.64; p=0.001; df=4). There were also contrast differences between each pair of comparisons: Battle Order to 10 kg (p=0.059; NS), 10 kg and SS kg (p=0.009); SS kg and 20 kg (p=0.001) and 20 kg and 30 kg (p=0.01).

Table 4.3 presents the task-by-task differences as determined by Tukey tests. For the most part, Pack C was preferred to Pack D. This was due perhaps to familiarity with Pack C or to its higher centre of mass (better for load control) or design (more lateral stability in the shoulders). When individual subjective responses to tasks were analyzed (Figures 4.28 to 4.32), there were significant differences in responses between packs on the following tasks: balance beam, branch duck, fence climb and the up ramp. These tasks required much greater lateral stability which could account for the subjective responses preferring Pack C.

Table 4.3 Significance of individual task-based subjective responses

	Between Packs	Between Loads	Significant Contrasts	P values for Contrasts
1a) Balance Beam	F=8.13; p=0.02; df=1	F=11.2; p=0.001; df=4	SS to 20kg 20 to 30 kg	(p=0.004) (p=0.002)
1b) Boulder Hop	F=4.04; p=0.075; df=1	F=7.73; p=0.001; df=4	SS to 20kg 20 to 30 kg	(p=0.04) (p=0.003)
2a) Over Log	F=3.97; p=0.077; df-1	F=9.27; p=0.001; df=4	10 to SS kg SS to 20 kg 20 to 30 kg	(p=0.05) (p=0.02) (p=0.002)
2b) Under Branch	F=14.31; p=0.004; df=1	F=21.95; p=0.001; df=4	10 to SS kg SS to 20 kg 20 to 30 kg	(p=0.003) (p=0.02) (p=0.007)
2c) Fence Climb	F=15.7; p=0.003; df=1	F=8.4; p=0.001; df=4	5to 10 kg 10 to SS kg SS to 20 kg 20 to 30 kg	(p=0.003) (p=0.003) (p=0.002) (p=0.001)
3a) Pylon Run	F=4.9; p=0.057; df=1	F=4.9; p=0.057; df=4	10 to SS kg SS to 20 kg 20 to 30 kg	(p=0.025) (p=0.047) (p=0.07)
3b) Up Ramp	F=6.9; p=0.03; df=1	F=10.2; p=0.001; df=4	10 to SS kg SS to 20 kg 20 to 30 kg	(p=0.01) (p=0.005) (p=0.034)
3c) Down Ramp	No difference	F=5.7; p=0.001; df=1	10 to SS kg SS to 20 kg 20 to 30 kg	(p=0.02) (p=0.024) (p=0.06)
4) Side Ramp	No difference	F=2.84; p=0.04; df=1	SS to 20 kg	(p=0.047)
5) Sum of Wall Touch	No difference	F=6.97; p=0.001; df=1	BO to 5 kg	(p=0.025)

* Listed below are the Figures 4.28 to Figure 4.32 to show mean results.

In Table 4.3, the majority of the tasks showed pack type differences with Pack C preferred over Pack D. Overall the load weights, there were significant differences in all tasks except the pylon run and side ramp. However, these significant differences were not between each load mass. The column entitled “P Values for Contrasts” were most frequently between the self-selected load and 20 kg load (9 times) and between the 20 kg Load and 30 kg load (8 times). This means that as the loads became heavier, the ability to differentiate subjectively between conditions became greater.

4.10 Subjective Responses to Various Task-Based Questions

After the timed circuit, subjects were asked to respond to the tasks with opinions of how the load and system affected their balance, mobility, agility and comfort.

4.10.1 Balance Beam Boulder Hop

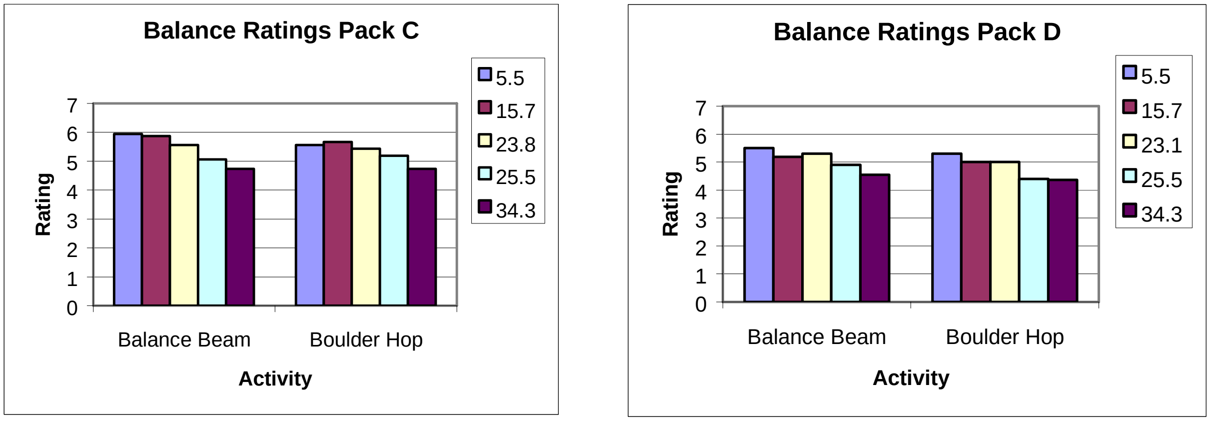

Figure 4.28 Comparison of Responses Pack C and D for each load for Task #1

4.10.2 Over/Under and Fence

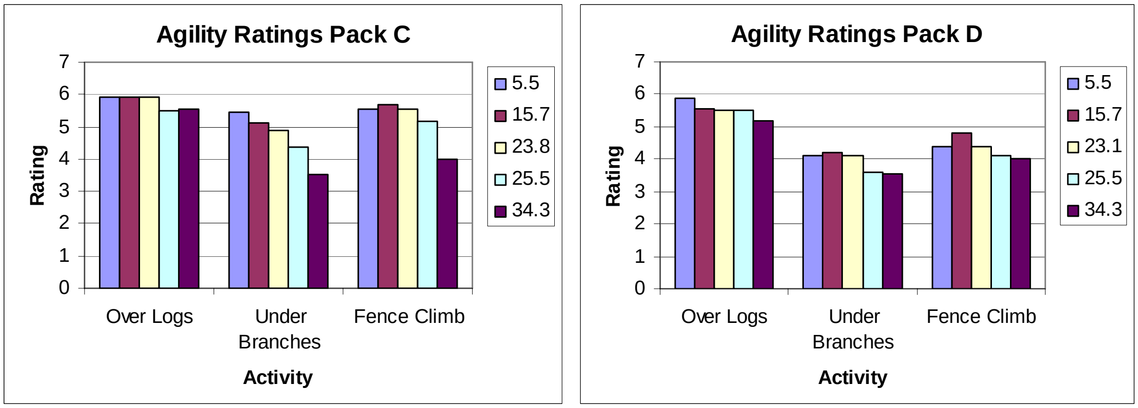

Figure 4.29 Comparison of Responses Pack C and D for each load for Task #2

4.10.3 Shuttle and Up/Down Ramp

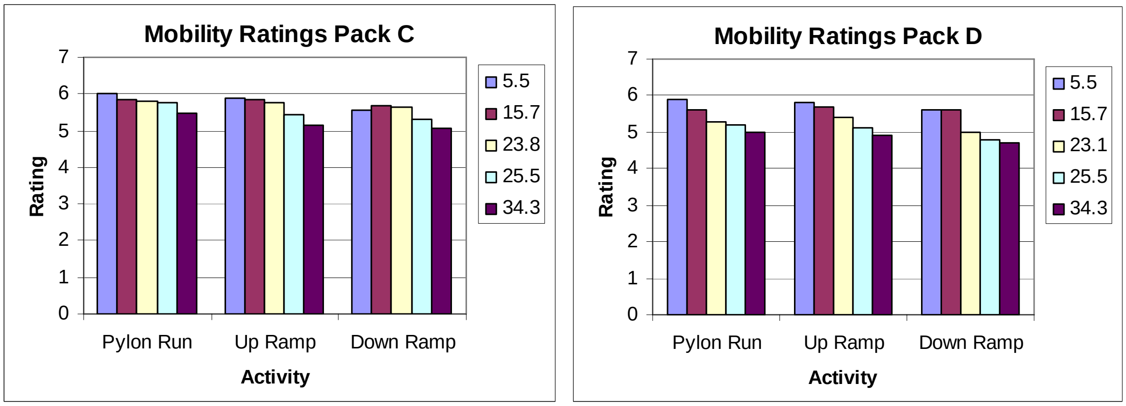

Figure 4.30 Comparison of Responses Pack C and D for each load for Task #3

4.10.4 Side Hill Slant

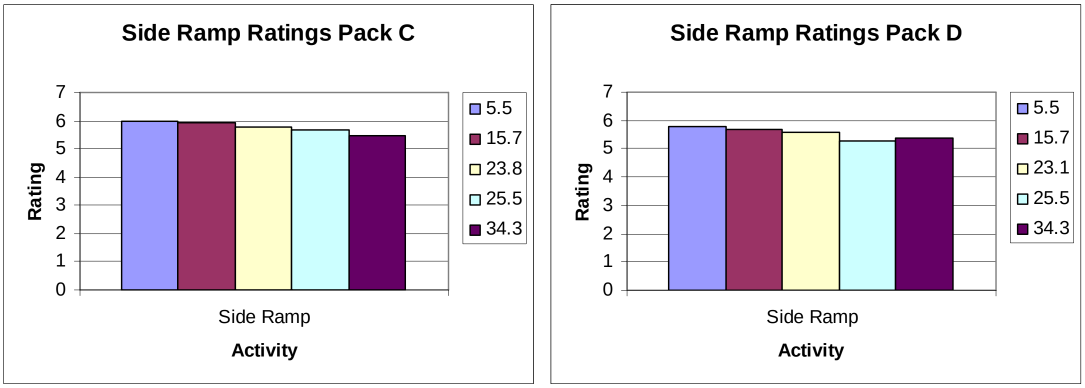

Figure 4.31 Comparison of Responses Pack C and D for each load for Task #4

4.10.5 Wall Touch Test

The wall touch task required the subject to make large trunk movements to touch a target placed at the knees and over the shoulders. As such, it required trunk control in the lateral, sagittal and torsional directions. Figures 4.28 show the subjective responses to Pack C and D.

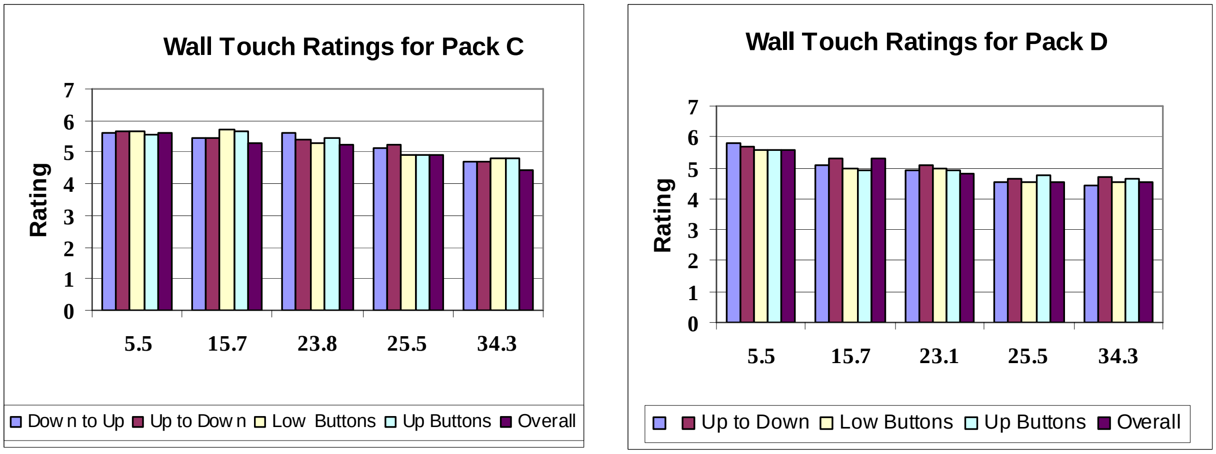

Figure 4.32 Comparison of Responses Pack C and D for each load for Task # 5

For the tasks, subjective scores ranged from a perfect 6/6 to 3.7/6. Almost all scores for the 34.4 kg load averaged a lower score than 5/6. Both packs were every good and very comfortable to the user. Nonetheless, the 34.3 kg load did drive acceptability below 5.

4.10.6 Comparison of General Ratings to Mobility

At the end of each load, there was a chance for the subject to rate the overall acceptability of the system. Four questions dealt with ease of controlling the LC System and four questions dealt with body comfort. Responses to these questions are shown statistically in Table 4.4 and in Figures 4.33 and 4.34 for Pack C and D.

Table 4.4 Statistical summary of subjective overview responses about mobility

	Between Packs	Between Loads	Significant Contrasts	P values for Contrasts
A) Control	F=14.24; p=0.004 df=1	F=9.16; p=0.001; df=4	BO to 15.5 kg SS to 25.5 kg 25.5 to 34 kg	(p=0.037) (p=0.025) (p=0.003)
B) Balance	F=17.6; p=0.002; df=1	F=17.4; p=0.001; df=4	BO to 15.5 kg 15.5 to SS kg SS to 25.5 kg 25.5 to 34 kg	(p=0.004) (p=0.031) (p=0.008) (p=0.001)
C) Mobility	F=66.8; p=0.001; df-1	F=13.5; p=0.001; df=4	BO to 15.5 kg 15.5 to SS kg SS to 25.5 kg 25.5 to 34 kg	(p=0.015) (p=0.037) (p=0.034) (P=0.001)
D) Agility	F=18.4; p=0.002; df=1	F=16.1; p=0.001; df=4	BO to 15.5 kg 15.5 to SS kg SS to 25.5 kg 25.5 to 34 kg	(p=0.037) (p=0.081) (p=0.017) (P=0.001)

In all cases Pack C was ranked superior to Pack D in the overview comments. There were also significant differences by load and almost all planned comparisons. It would seem that the overview summaries are more discriminating then the task by task questionnaires. Scores averaged from 6/6 to 3.9/10 on this overview. Future work would not need to include individual circuit tasks questionnaires.

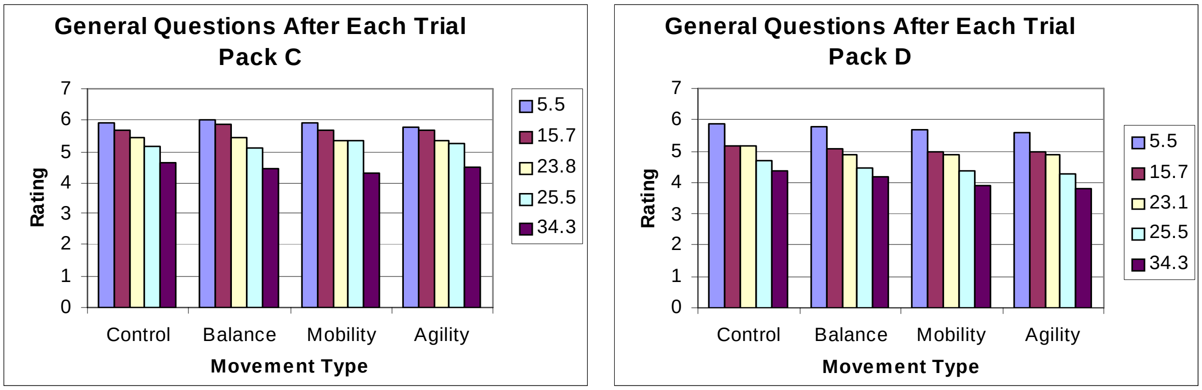

Figure 4.33 Comparison of General Responses to Movement with Pack C and D after each Trial

4.10.7 Comparison of General Ratings to Comfort

Table 4.5 and Figure 4.34 show the subjective responses to comfort. Subjects rated Pack C more appropriate for overall comfort and comfort in the shoulders and neck. Perhaps this is due to load lifters that were present on Pack C but not Pack D. There was no difference in waist and lumbar spine comfort or thermal comfort between packs.

Load had a large bearing on subjective comfort scores for both packs. These differences were only occasionally significant between loads as evidenced in planned comparisons.

Table 4.5 Statistical summary of subjective overview responses about comfort

	Between Packs	Between Loads	Significant Contrasts	P values for Contrasts
A) Overall	F=26.8; p=0.001 df=1	F=11.1; p=0.001; df=4	SS to 25.5 kg 25.5 to 34 kg	(p=0.034) (p=0.001)
B) Shoulders and Neck	F=6.52; p=0.034; df=1	F=14.1; p=0.001; df=4	BO to 15.5 kg SS to 25.5 kg 25.5 to 34 kg	(p=0.002) (p=0.003) (p=0.001)
C) Waist and Low Back	Not Significant	F=6.82; p=0.002; df=4	BO to 15.5 kg 25.5 to 34 kg	(p=0.043) p=0.012)
D) Thermal	Not Significant	F=3.5; p=0.018; df=4	25.5 to 34 kg	(p=0.024)

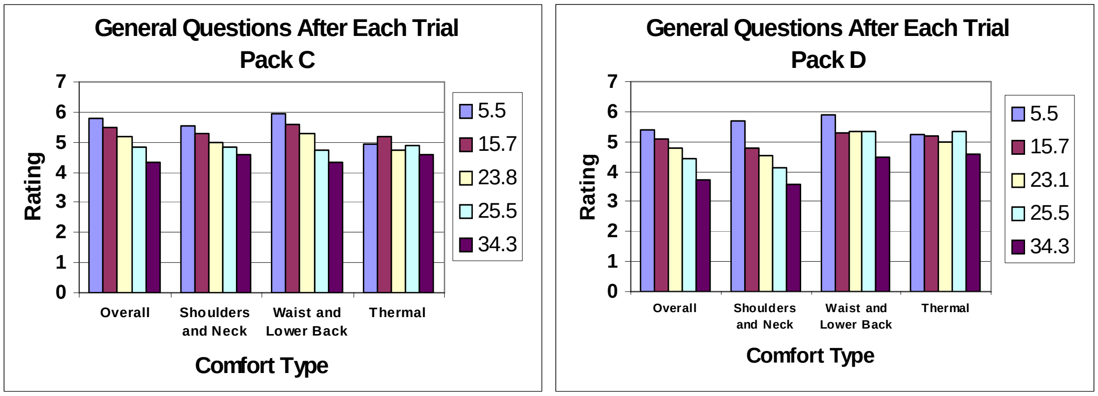

Figure 4.34 Comparison of General Responses to Comfort with Pack C and D after each Trial

4.11 Final Comparative Questionnaire for Packs

In order to obtain an overall comparison between the Pack C and D, subjects were asked to complete a final comparative questionnaire in which they rated the two packs on a ten point scale for comfort, balance, load control and fit of both packs in circuit and marching conditions. A higher rated score is a better score. These results are summarized in the following graphs:

When packs were compared, Pack C received a higher comfort rating in both tasks of circuit and marching conditions (Figure 4.35). Several subjects mentioned the presence of shoulder and back pain more so in Pack D than Pack C. As Pack D was offset further from the body and did not have load lifter straps to create an upper body snugness, it is not surprising that this evaluative comment would prevail. In addition, subjects commented that Pack C fit tighter against their body and was effective in reducing bouncing and pain.

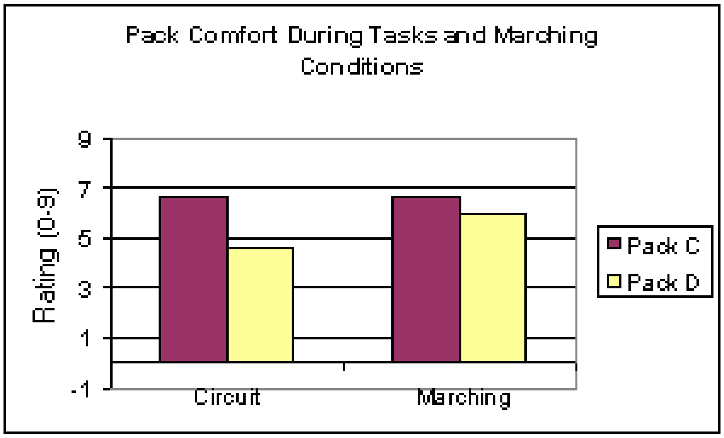

Figure 4.35 Comparison of Pack C and D with regard to comfort during tasks and marching.

When subject balance was compared, Pack C was rated higher than Pack D in both tasks in circuit and marching conditions (Figure 4.36). Subjects commented that more weight shifting occurred with Pack D, which led to decreased balance during circuit performance more so than in marching conditions.

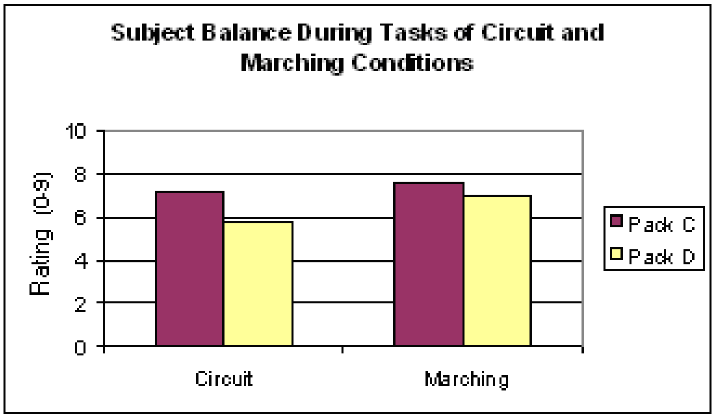

Figure 4.36 Comparison of Pack C and D for subject balance in tasks and marching.

Pack C received a higher rating on load control when compared to Pack D, particularly under circuit conditions (Figure 4.37). Several subjects attributed Pack D's decrease in load control to too much movement and shifting of weight. While Pack D still managed to achieve a "good" rating, many subjects listed the Pack C as "excellent".

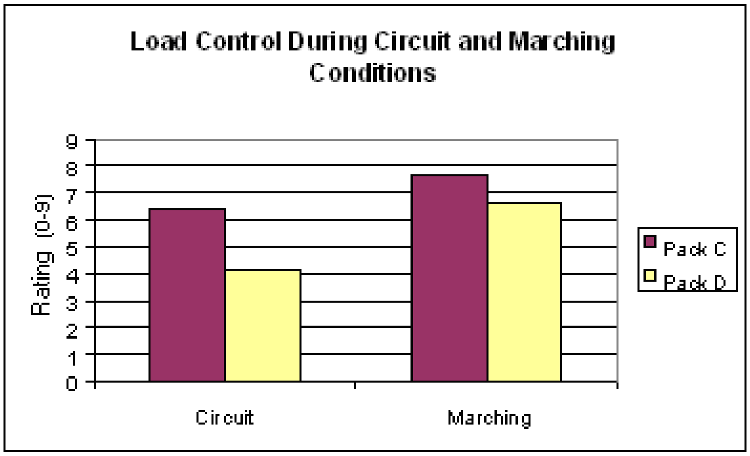

Figure 4.37 Comparison of Pack C and D for load control in task and marching conditions

When the fit of the pack was considered, Pack C once again scored higher than Pack D during both tasks in circuit and marching (Figure 4.38). When asked to compare the two packs, a common reply was that Pack C had a much snugger fit than Pack D, which contributed to better balance and a better feel. The increased distance between the load carriage and pack in the DFS System was also mentioned as a drawback to the fit of Pack D.

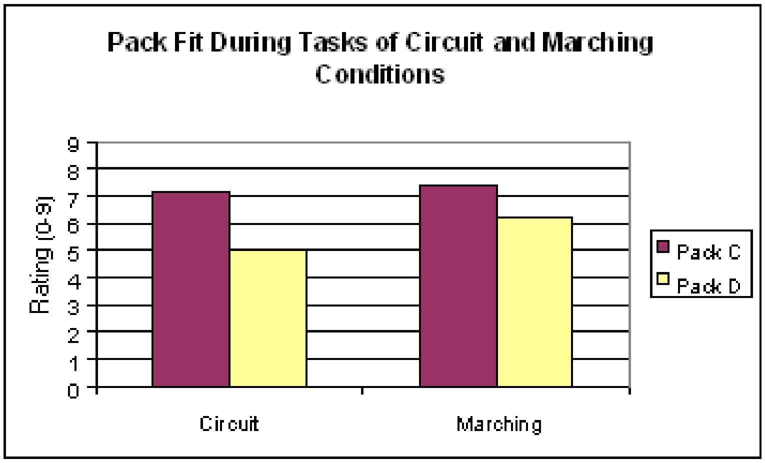

Figure 4.38 Comparison of Pack C and D with regard to pack fit in tasks and marching conditions

Figure 4.39 summarizes the four previous figures into one overall comparison. It is clear that Pack C was assessed as being superior to Pack D with regard to the comfort and fit of the pack, as well as load control and subject balance. Subjects included general comments regarding their choice of one pack over the other, stating that although Pack D felt like it distributed the weight more evenly, the CTS System was a snugger fit and improved balance due to less movement and load shifting.

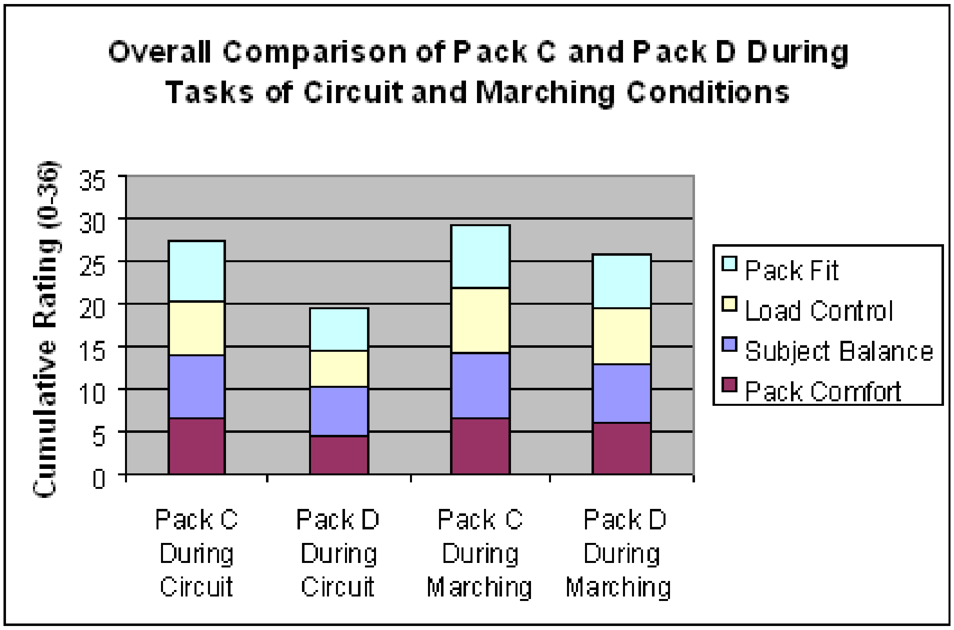

Figure 4.39 Overall comparison of Pack C and D with respect to comfort, balance, load control and fit during circuit and marching conditions

5. Examination of Pack Forces of Standing Posture

Each subject was photographed under each condition from the side view to determine their standing postural adjustments to load. In addition, the photographs allowed us to examine the forces experienced by the shoulders and lumbar areas using the Static Biomechanical Models from Phase I (Stevenson et al., 1995, MacNeil, 1996) and Phase II (Pelot et al., 1998, Rigby, 1999) respectively. For each subject, the centre of gravity of the pack and person were determined. The person without a pack would have had the line of gravity fall through the ear, shoulder, hips, knees and slightly in front of the ankles. This was reasonably reflected for Battle Order where half of the 5.46 kg load mass was in the TAV and half in the day pack. However, when wearing a rucksack, the person compensated by shifting the upper body forward to remain in balance. A demonstration of this compensation can be seen in Figure 3.7. The goal of this subsection was to determine body compensation mechanics and body reaction forces that were experienced when wearing a backpack and to see when there was deterioration in performance.

5.1 Postural Adjustments based on Load and Pack

A person may often compensate for the load by leaning forward at the waist. This posture is often assumed when the centre of gravity of the pack is lower or the load is heavier (Kinoshita, 1985, Johnson et al., 2001). For this analysis, the upper body lean angle was calculated by the angle subtended by the ear, hip and vertical plane. Based on a two way repeated measures ANOVA for pack and load, there was a significant difference in upper body lean angle between Pack C and D (F=21.2; p=0.006; df=1). There was also a significant difference between loads for both Pack C and D (F=38.7; p=0.001; df=4). For Pack C, using planned comparisons, there was a significant difference between Battle Order (5.46 kg) and all other loads and between 34.3 kg load and all other loads. Within Pack D, all conditions were significantly different in upper body lean angles between all loads (p=0.001).

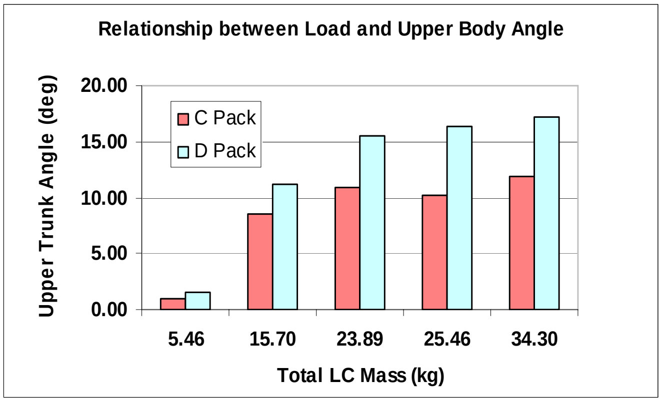

Figure 5.1 Comparison of upper body lean angle by pack and by load

Another strategy that is sometimes used to compensate for additional load on the back is to counterbalance with the head. For this analysis, the head angle was calculated by the angle subtended by the ear, shoulder and vertical plane. Figure 5.2 shows the results of this analysis. There was no significant difference by pack type or load condition.

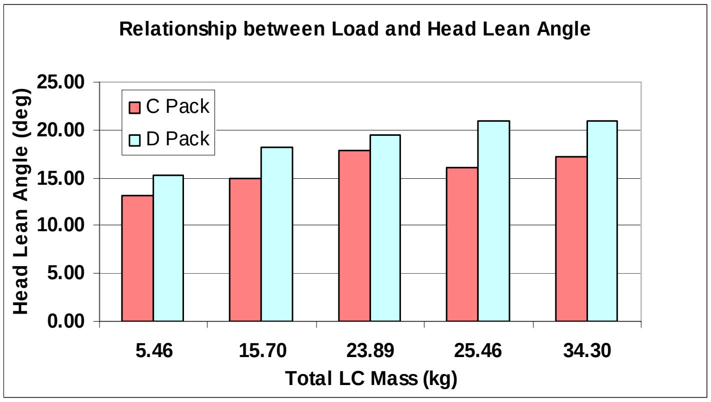

Figure 5.2 Comparison of head lean angles by pack and by load

This may appear incorrect given the apparent increase in head angle with increasing load. But subjects may be compensating by a combination of upper body and head lean angles. To examine this possibility, the two angles were summed to create a composite upper body adjustment score. Using this method, there was no significant difference between packs but there was a significant difference between loads (F=9.0; p=0.001; df=4). When planned comparisons were made, there was a significant difference between all loads except the 25.5 kg and the 34.3 kg loads.

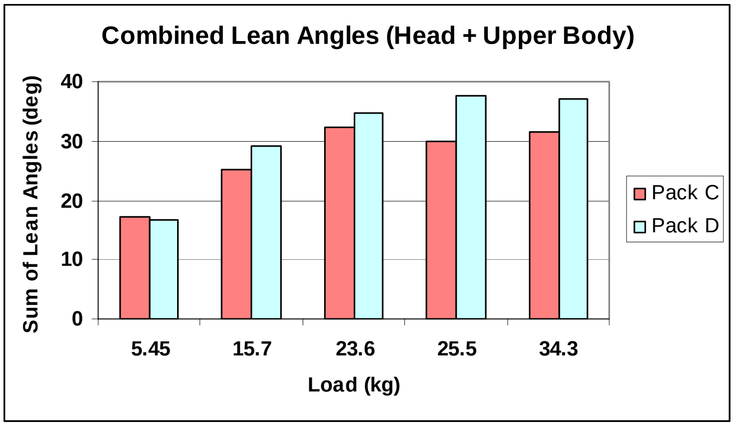

Figure 5.3 Combined Effect of Lean Angles by pack and by load

5.2 Shoulder Reaction Forces and Discomfort

5.2.1 Relationship of Mass to Shoulder Reaction Force

In previous reports, Stevenson et al. (1995) recommended that, to reduce discomfort to a minimum, the shoulder reaction forces should be 145 N/shoulder or 290 N for both shoulders. Figure 5.4 revealed that only the 34.4 kg load exceeded the recommended shoulder reaction forces. When comparing the packs using a two-way repeated measures ANOVA, there was no significant difference between packs (p=0.093) but there was between loads (F=344.3; p=0.001; df=4) as well as an interaction effect between pack and load (F=29.3; p=0.001; df=4). Pair-wise comparisons revealed that all loads were significantly different from one another.

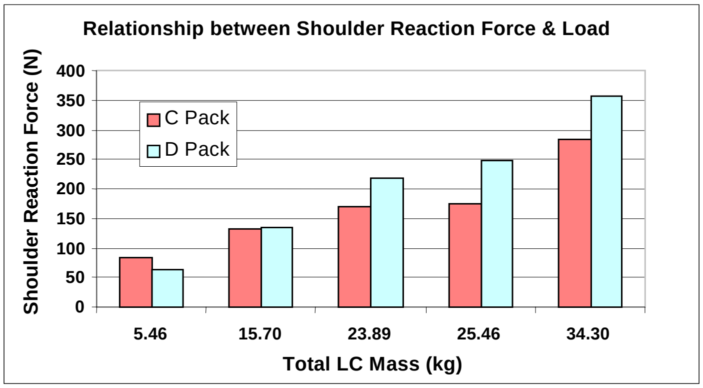

Figure 5.4 Comparison of Shoulder Reaction Forces by Load and by pack

5.2.2 Relationship of Shoulder Reaction Force to Discomfort

When the shoulder reaction forces were compared to subjective responses of discomfort, discomfort scores explained 31% of the variance in the data (Figure 5.5). Not everyone answered the body discomfort front and back pictograms. When responses were averaged, then the relationship became much clearer (81% variance explained), suggesting that averaging was necessary to use subjective discomfort scores wisely. It also indicated that when average scores exceeded 4 on a discomfort scale, there was reason to be concerned.

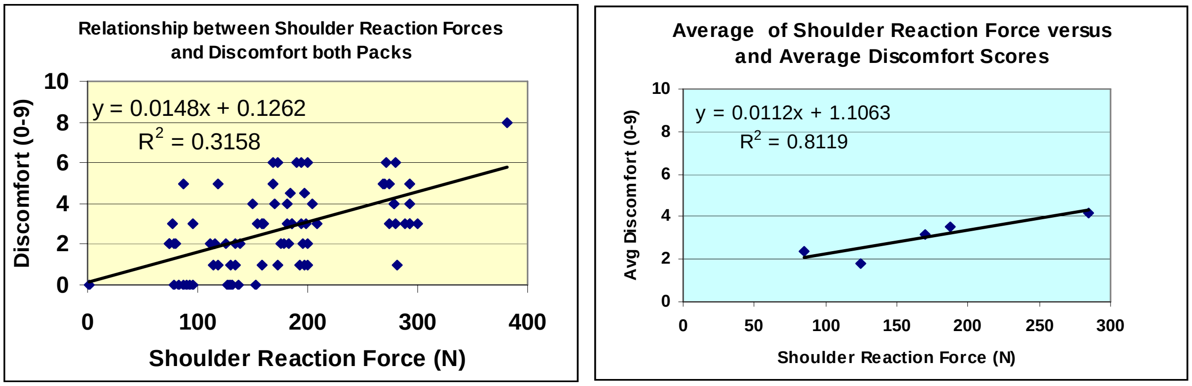

Figure 5.5 Discomfort scores in comparison to shoulder reaction force across both packs for:

(a) individuals and (b) mean of the group

5.3 Lumbar Reaction Forces and Discomfort

5.3.1 Relationship of Mass to Lumbar Reaction Force

For lumbar reaction forces, the recommended value was 135 N to reduce the amount of discomfort (Stevenson et al., 1995). This value was derived from the shoulder-based model and may have been a conservative estimate. In this study, the Battle Order load (5.45 kg) and the light load (15.7 kg) were below this value. There was a significant difference between packs (F=22.1; p=0.005; df=1) and between loads (F=379.8; p=0.001; df=4) with a pack by load interaction (F=18.4; p=0.001; df=4). In paired comparisons, all loads were significantly different (p=0.001).

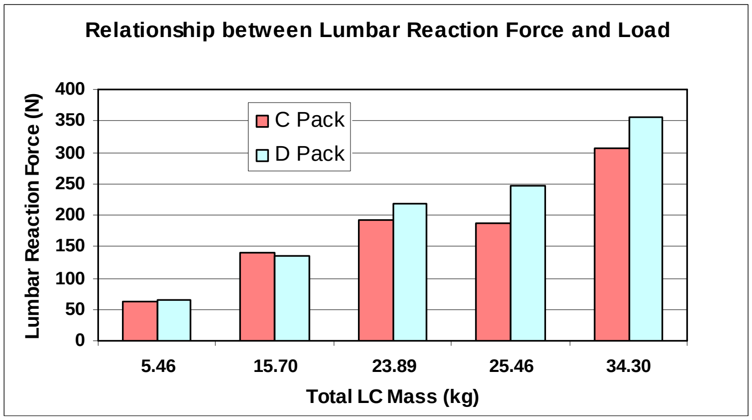

Figure 5.6 Comparison of lumbar reaction forces by load and by pack

5.3.2 Relationship of Lumbar Reaction Force to Discomfort

Reported lumbar discomfort of soldiers across both packs was compared to lumbar reaction force as calculated using the biomechanical model. Few individuals reported lumbar discomfort. In addition, the correlations were poor between reported discomfort and lumbar reaction force (individuals r^2=0.05; group r^2=.59) (Figure 5.7). This indicates a couple of concerns: perhaps the previous research with a six km march is necessary to see

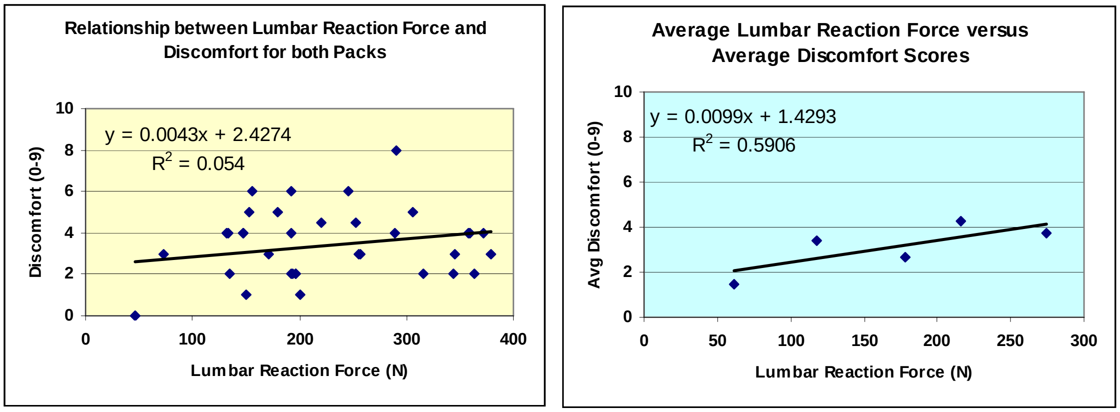

Figure 5.7 Discomfort scores in comparison to lumbar reaction force across both packs for: (a) individuals and (b) mean of the group

reported discomfort as these packs were only worn for 20 minutes. Also, the recommended limit could be too low for shortened time durations. This concept is shown in Figure 5.8 where the longer a tissue is exposed to pressure or force, the less it is able to endure loads. It is also possible that these packs did not incur much discomfort.

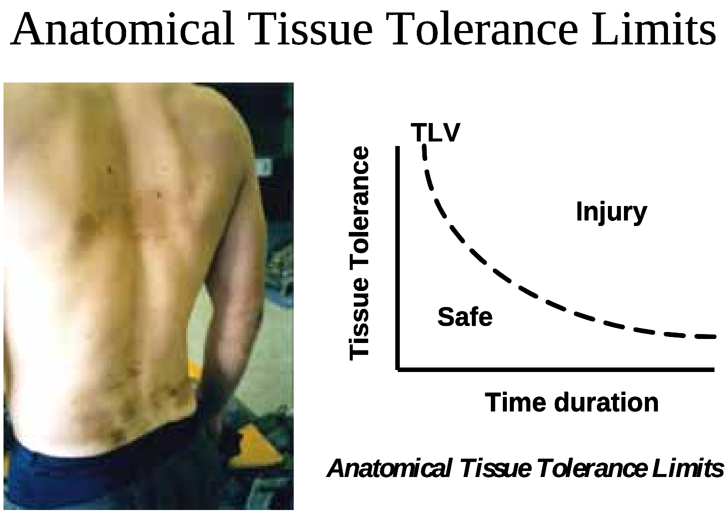

Figure 5.8 Conceptual Drawing of human tissue tolerance curve.

5.4 Ratio of Body Forces to Load

One of the interesting comparisons is to examine the amount of reaction forces experienced by the subjects. Figure 5.9a and b show the body forces in relation to the load weight in Newtons and as a ratio of the load weight respectively. As the load increases, so do the body reaction forces. Except for the Battle Order load, the pack exerts onto the body approximately 1.75 times whatever weight is in the pack. Considering the Battle Order biomechanical model is different than the backpack situation, this could be why we see this anomaly in body reaction forces to load (in Newtons).

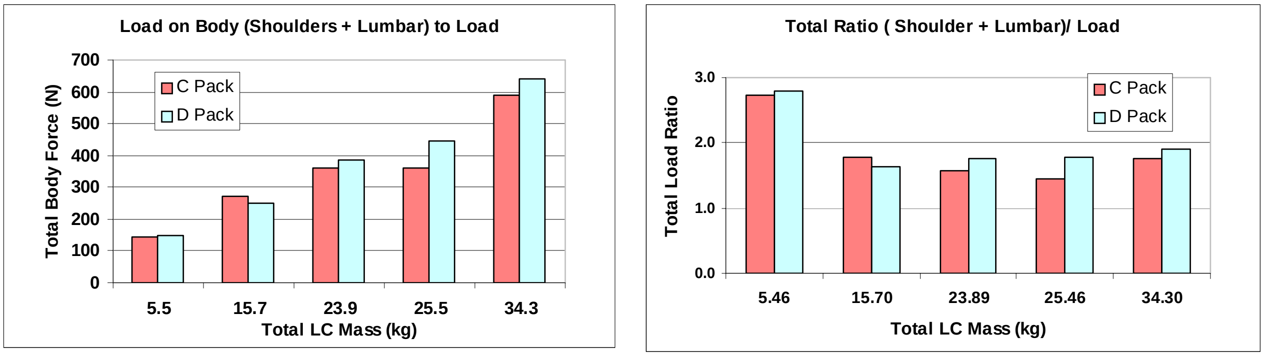

Figure 5.9 Ratio of load on the body to a) reaction forces and b) ratio of load

Both Pack C and D had many of the same features. As a result, contact points of frame sheet to body would be the same for both packs. It is interesting to note that the proportionate weight on the shoulders and waist is almost 50% to each area. Perhaps the subjects would have experienced less shoulder discomfort if they had been able to transfer more load to the waist belt. Subjects did not have the packs on long enough to go through many adjustments. If they had used the adjustment features of the pack more there may not have been the same level of discomfort at the shoulders.

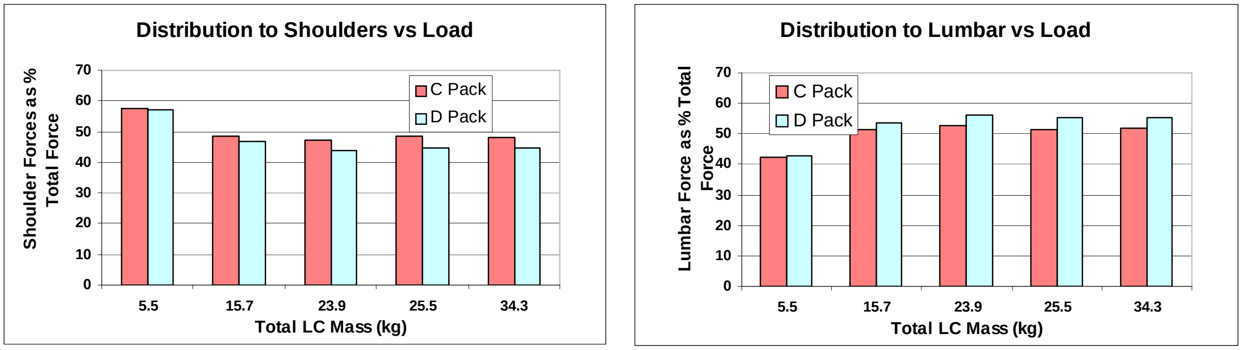

Figure 5.10 Percent Force on the (a) shoulders and (b) waist belt Hips in relationship to load

5.5 Percentage Postural Change with Load

As with the timed and MVO_2 measures, we wanted to express changes as a percentage increase from Battle Order. This became problematic if one examines Figure 5.11 below. The Battle Order condition had half the payload at the front and hence the body lean angles were very small. In addition, a different biomechanical model was used for Battle Order and the remainder of the conditions. Hence it was decided to express all percentage increases from the 15.7 kg load. We were still looking for situations where there is a drop-off in performance in excess of 15%.

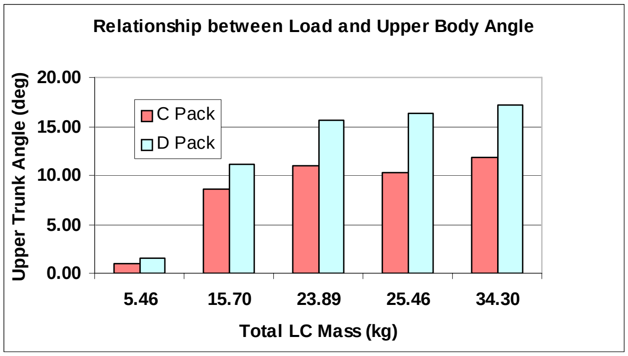

Figure 5.11 Differences between Battle Order and other conditions too great to use as a baseline for biomechanical variables.

5.5.1 Postural Change with Load

In Figure 5.12 below we can see that the person is actually leaning less with heavier loads. In the standing posture, the subject has the potential to use the pack as a counterweight and thus not be pulled forward by the load. If the data had been taken when the person was walking, then we would have seen increased loads because the subject must place the centre of gravity in front of the feet in order to walk. In future studies, body lean angle should be assessed during marching, not standing posture.

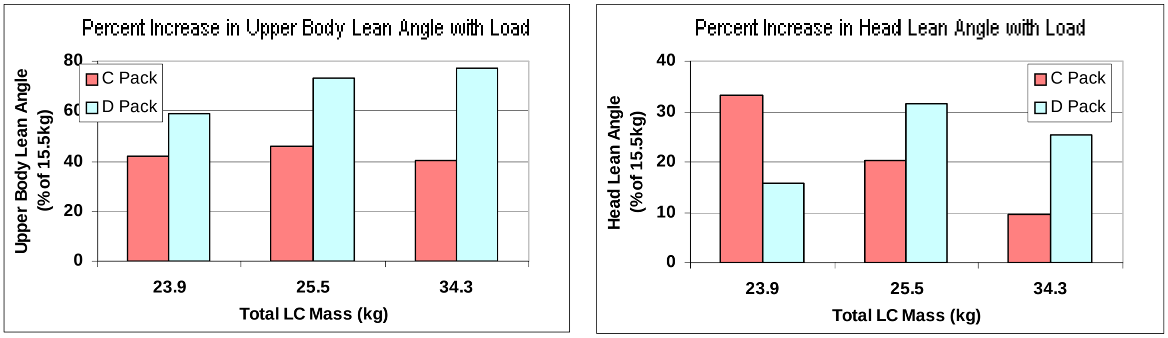

Figure 5.12 Percentage of (a) upper body and (b) head lean angle in relation to the 15.5 kg load.

5.6 Increases in Body Reaction Forces to Load

The largest increase in the shoulder and lumbar reaction forces occurred between the 25.5 kg and 34.3 kg (Figure 5.13). In both cases the reaction force jumped up to over 100% of the 15.5 kg load. As most subjects also found the 34.3 kg load difficult from a physiological standpoint, then this weight must represent a point where subjects can no longer use tradeoffs in pace and oxygen consumption. In addition, their subjective discomfort scores also rise above 4 on a 0-9 discomfort scale. Seeing the percent increase can be used to set recommended guidelines for efficient movement of troupes with minimum rest periods to avoid discomfort.

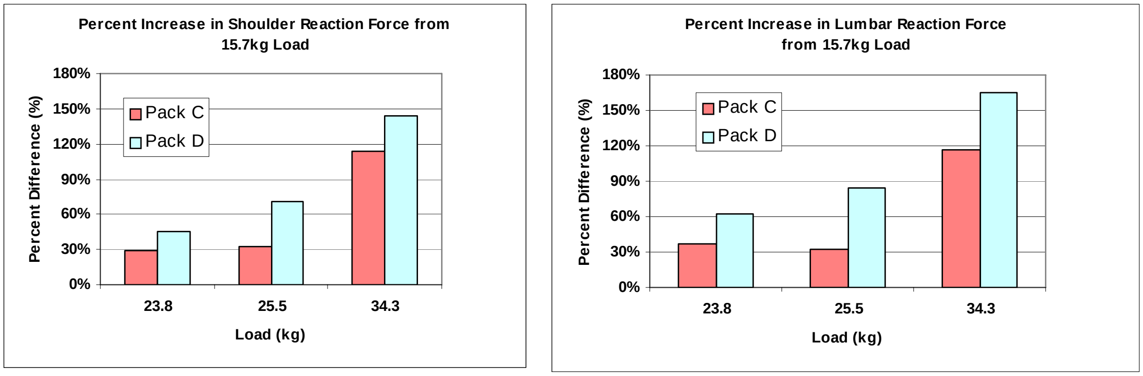

Figure 5.13 Percent increase in (a) shoulder and (b) lumbar reaction forces with load.

6. General Discussion

There are several important features about this study that are different than others in the scientific literature. Each of these will be explained in detail below.

Normally other studies have controlled the workload or pace and observed the response of aerobic demand to load. Studies have shown that during dynamic exercise at a constant speed, oxygen uptake increases linearly with the amount of weight carried (Borghols et al. 1978, Patton et al. 1991). It has also been established that when speed remains constant, the energy expenditure per kg of load carried is equal to the energy expenditure per kg of body weight up to at least 30 kg (Goldman and Iampietro 1962, Soule and Goldman 1969). In this study we varied both load and pace to see how subjects adjusted without the pressure of being forced to adjust oxygen consumption as their only method of control. In 16/20 cases, subjects tried to keep their oxygen consumption constant and accommodated by moving at a slower pace. The four subjects who were of varying fitness levels, allowed oxygen consumption to climb and tried to maintain a constant pace throughout all trials. In each case, this was their first day of testing and they did not repeat this pattern on the second day. Across all subjects, the pace over the course slowed by 20 % from Battle Order to the heaviest load. At the heaviest load of 34.4 kg, subjects could not maintain a steady state oxygen consumption and it rose 10% with the time increasing 20% over a Battle Order pace. If walking on flat terrain, the drop-off in performance was only 5% to 10 % from lightest to heaviest load; however, if performing complex tasks, performance times dropped off 10% to 30% over Battle Order conditions.

In this study we also added a self-selected load using a psychophysical approach. The purpose of this strategy was to determine the maximum loads experienced subjects were willing to carrying when they made the determination. On average the weight selected was 23.8 kg, close to the medium weight we assigned for standardized loads. For the self-selected load, the oxygen demand was at 55% MVO_2, a 13% increase from Battle Order conditions. The shoulder reaction forces considered acceptable by subjects were between 160 N and 220 N. This level was less than the recommended guideline of 290 N for both shoulders and rated by subjects around 3+ of 9 on the discomfort scale. For lumbar reactions forces, the self-selected load was between 195 N to 220 N, much higher than the lumbar reaction force of 135 N soldiers indicated was problematic in the first study (Stevenson et al, 1995). This elicited an average discomfort of 3+ on a 9-point scale. Perhaps the packs in the first study accentuated the feelings of lumbar discomfort because the task was a 6 km march, or perhaps these packs had a superior waist belt design. Regardless, there were few signs of problems in the waist belt area. Further research should be done to determine if the recommended level of force in the lumbar region is too conservative as a lumbar reaction force guideline.

The heaviest load condition was 34.3 kg. Regardless of fitness level, this load taxed subjects. Circuit times of ~ 650 seconds for Battle Order jumped to ~800 second for the heavy load. Oxygen demand also jumped from ~ 50% to 60% of predicted MVO_2. This is a 20-25% increase in time and a 15% to 20% increase in oxygen demand. Although both marching and tasks required more time to complete, there was a

3:1 ratio of added time for tasks to marching. The shoulder reaction forces were ~ 250N to 360 N, near the recommended force limit of 290 N. The lumbar reaction forces were ~ 300 N to 350N much beyond the recommended limit of 135 N. These values were 110% to 160% greater for both reaction forces than for the light (15.5 kg) load. This study can serve as the basis of human data from which regressions models can be generated to predict total time needed to complete a mission, given terrain difficulty, load, maintaining 55% MVO_2, and including a number of rest breaks. Because this was a shortened task, data needs to be gathered in determining the number of rest breaks needed and whether they are based on muscular fatigue or metabolic requirements. This information may be collected through interviews with platoon leaders or through scientific study.

In the test battery, we asked subjective opinions about each circuit item. (Section 4.9 (.1-.5)). However, when we asked for summary information about the trial (Section 4.9.7), it revealed the same information with better discrimination on the overall pack. This would suggest that in future trials, the data be taken as summary information. It is possible to understand the subjects' likes and dislikes about a system with primarily summary information. In the final comparative questionnaire, Pack C significantly out-ranked Pack D on comfort, balance, load control, and fit during both the tasks and the circuit. In terms of comfort, Pack C was significantly more comfortable overall and in the shoulder regions. This is probably because Pack D lacked the load lifter straps and may have been more responsive to pack accelerations than Pack C.

The important aspect of taking lateral standing posture photographs is to determine the shoulder and lumbar reaction forces. At the same time, these photographs allowed us to determine postural adjustments that occurred due to load. These were quantified in terms of head and upper body posture. After examination of the data, it became obvious that only walking body lean postures would be satisfactory because in standing, the pack was used as a counterweight to the upper body. Hence the angles were not necessarily much poorer with increased load. This would suggest that in future studies, the postural changes should be monitored during walking since the person must get their centre of gravity ahead of their feet in order to walk. Only here would one see the extent of forward lean required due to load. When this lean is required, it is hypothesized that the heavier loads would have the greatest body lean angle. It is also hypothesized that greater erector spinae muscular effort is needed to prevent the subject from falling forward. It is recommended that future dynamic biomechanical modeling become more focused on capturing the body lean angle as part of the overall biomechanical model.

In summary and after this research, it seems appropriate to recommend that the biomechanical model should be directed more toward developing standards than working as a design tool. This biomechanical model could be integrated into the output from the portable system so that we can get a measure of energy cost, understand postural lean angles and calculate the reaction forces needed by the shoulders and waist belt. Then, once the model is built, we could test soldiers over longer periods [e.g. a) annual army fitness test or b) on a four hour or c) all day mission].

7. Conclusions and Recommendations

7.1 Conclusions

It must be realized that this report serves as a solid half way point in documenting the effects of pack type and load on many variables: aerobic consumption, timed performance, body part discomfort, posture, shoulder reaction force, lumbar reaction force. In addition we have examined the percent of drop-off in these measures by pack and by load. What we have not yet analyzed are matters far more germane to the dynamic biomechanical model. For example, comparing the strap force readings taken during human testing to those calculated by the static biomechanical model, and validating the dynamic biomechanical model using the LC Simulator and the output from the two triaxial accelerometers. These will become objectives in the next phase.

Relationship of aerobic capacity and circuit duration to load. Normally other studies have controlled the workload or pace and observed the response of aerobic demand to load. In this study we varied both load and pace to see how subjects adjusted without the pressure constraint of being forced to adjust oxygen consumption as their only method of control. Using two and three-way repeated measures ANOVA with packs, loads and laps, there was no significant difference between packs. However, with regard to aerobic demand, there was a significant difference between loads ($p=0.001$), between laps ($p=0.001$) and between tasks ($p=0.001$). There was a decrease in performance time for each task with load ($p=0.001$) but not between packs. In comparison to Battle Order, there was a 5% to 15% drop-off in time during laps, which was significant by load ($p=0.005$) and almost by pack ($p=0.06$). Similarly, the drop off in performance for task times was 11.6% to 29.2% for 15.5 kg to 34.3 kg respectively.

The subjects' aerobic response differed significantly by load during the tasks ($p=0.004$), however, only the 34.4 kg load caused greater than a 15% increase in MVO_2 from the Battle Order baseline. The aerobic demand was 55% MVO_2 at Battle Order and rose to 60% MVO_2 during the 34.4 kg load. During the laps, aerobic demand increased approximately 15% for the intermediate loads and 27.1% during the 34.4 kg load. Almost all subjects tried to keep oxygen consumption constant and accommodate by moving at a slower pace.

The conclusion from this component of the study is that subjects prefer to control their aerobic demand and make a concurrent adjustment to pace to accomplish this change. It is unclear if this response is due to the protocol of allowing a self-controlled pace or another factor. The same protocol should be repeated at longer durations of marching to determine if this balance remains the same. As the 34.4 kg workload did not allow subjects to maintain the pace-aerobic demand balance, the circuit demand was considered the upper end of loads to be tested.

Relationship of subjective responses to load. Within the report, subjects were queried about their pack control, balance, mobility and agility during the tasks with summary questionnaires at the end of the circuit. There was a significant difference between packs (p=0.002) and between loads (p=0.001). Pack C was preferred over Pack D on almost every variable. The pack preference was less convincing for comfort where overall comfort, shoulders and neck, waist and low back and thermal comfort were assessed. This was not surprising as the same shoulder straps, frame sheet and waist belts were used for both Pack C and Pack D. In a 6 point subjective questionnaire, the highest average score was 4 or moderate discomfort. There was a drop off in comfort of 12.5 % from 5.6 to 4.9 over this short course. It was expected that subjective ratings would be greater when task durations are lengthened to more military-like distances.

Subjective ratings are an important aspect of pack and load evaluation. It was concluded that there were more evaluative questions than necessary as the final questionnaires after circuit completion tended to capture the depth of the subjects' perceptions better than individual task based assessments. In future studies fewer intermediate assessments would be appropriate.

Relationship between shoulder and lumbar reaction forces and load. Each subject was asked to stand perpendicular to a digital camera and one photograph was taken per load. Knowing the weight in the pack, dimensions of the pack and the lean angle of the soldier, it was possible, using static biomechanical models by McNeill (1996) and Pelot (1998), to determine the shoulder and lumbar reaction forces needed to counterbalance the weight of the pack. In previous reports, Stevenson et al. (1995) recommended that, to reduce discomfort to a minimum, the shoulder reactions forces should be 145 N/shoulder or 290 N for both shoulders and 135 N for lumbar reaction force. For the shoulders, there was no significant difference by pack but there was between loads (p=0.001). For Pack C the shoulder reaction force during the heaviest load was 280 N and for Pack D was 355 N. These were increases of 120% to 150% over the light load. For the lumbar reaction forces, there was a significant difference between packs (p=0.005) and between loads (p=0.001). Pack C averaged 300 N and Pack D averaged 350 N. Since the original guideline was developed around a 6 km march with 34 kg, it is not surprising that soldiers would be able to tolerate higher load for shorter durations.

It appears that the recommended limit for the shoulders may be correct with a good pack design as even the 34.4 kg load was under the recommended shoulder reaction force limit of 290 N. However, the recommended lumbar limit may be too low at 135 N. Very few soldiers complained about discomfort in this region, perhaps due to good pack design. The lumbar reaction force needs to be re-evaluated in light of these findings. Both packs in this study used a substantial waist belt to distribute the load evenly onto the lumbar and hip regions and these results may be due to a successful distribution of this lumbar load.

Relationship between subjective discomfort and body reaction forces. In previous reports, the recommended guidelines were based on the relationship between discomfort and shoulder and lumbar reaction forces. There were few complaints relative to longer distances of load carriage; nonetheless a regression analysis was repeated. The level of discomfort at the heaviest load averaged 4+ (moderate discomfort) on a 9 point scale. The relationship was strong (r^2 = .91) for the shoulder reaction force (SRF) with less explanatory power (r^2=.61) for the lumbar reaction force (LRF). Combined SRF across both packs were at 290 N at the 34.4 kg load and LRF averaged 330 N. One concern with accurate interpretation of these data was the shortness of the circuit in comparison to typical military missions.

It is hypothesized that there will be a relationship between the biomechanical variables, duration of a task and load. It is also hypothesized that there will be a strong relationship between psychophysical measures and biomechanical measures that are both affected by load and pack design. These relationships will allow the development of a biomechanical factor that can be used in the establishment of a load conditions limit that is appropriate for different types of missions.

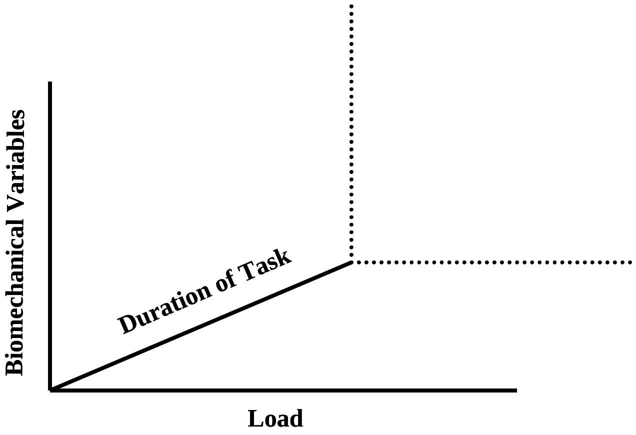

Figure 7.1 Conceptual approach to the development of a biomechanical factor.

Based on data gathered to date, it is possible to draw one curve on the axes in Figure 7.1. However, only one set of data has been collected. It is recommended that field trials be commissioned to take the same measures, including aerobic demand measures, under conditions of military marching pace for longer marches and under varying loads: such as, a) length of the annual army fitness test, b) on a four hour and/or c) all day mission. These field trials should also have an objective performance measure at the completion of the march. These data will be used to generate load-time-biomechanical 3D curves that are anchored on the acceptable tolerance limits of the average soldier.

7.2 Recommendations

Based on the conclusions, listed below are recommendations suited to future developments of a dynamic biomechanical modeling. This model will be based on human input data and experiences gained from this analysis of human trials.

1. The 34.3 kg load stresses both the cardiovascular system (60% MVO_2), the shoulder reaction forces (X =283 N), lumbar reaction force (305 N) with an average subjective discomfort score of 4.2 with a scoring range from 0 to 8. As this task lasted only 792 ± 67 second or 13.2 ± 1 minutes, it is believed that a load any greater than 34.4 kg (75.7 lbs) will be too heavy for sustained marching but quite tolerable for marches of shorter durations.

   It is recommended that the load of 34.4 kg become the upper limit of testing in order to develop a recommended load carriage limit (LCL) for military personnel. Establishment of an upper limit should be set using the measures from this study, the scientific literature and a future study required for its development. The military should consider if they wish to have an essential task (normally affected by fatigue) immediately after the march.

2. If given the freedom to choose, subjects will walk at a slower pace in order to maintain their oxygen consumption at a constant level. During this short and demanding circuit, subjects were working 55 % to 60% of their aerobic capacity, more than the level expected of heavy work in physically demanding job (Astrand and Rodall, 1982). As this was a 10 to 15 minute circuit where soldiers selecting the fastest possible pace they could sustain for eight hours across different loads, one must speculate and ultimately validate the responses to loads under variable distances.

   It is recommended that, after several laboratory tests and further developments using the portable system, field trials be conducted to take the same measures of heart rate, timed performance and whole body acceleration under variable loads at standard military marching paces. (Subjects should also be asked for their self-selected load but not complete that task). These field trials should also have an objective performance test at their completion. These data will be used to generate the biomechanical factor necessary to develop a load conditions limit profile as in Figure 7.1. These data will be validated by use of psychophysical factors as well as objective criteria.

3. Given the importance of self-reports of discomfort scales, it is important to validate these scales with meaningful anchors. In order to determine shoulder and lumbar limits, specialized testing jigs can be constructed to apply the load directly onto the shoulders or lumbar spine. Then, in a laboratory setting, variable loads and durations can be sampled and a subjective discomfort scale used to record levels of discomfort. This will permit better determination of subjective data in future field trials.

It is recommended that a specialized jig be developed and in-laboratory studies be conducted to evaluate subjective responses to pressure in the shoulder and lumbar area. These data can be used to develop a better interpretation of subjective responses.

4. All data represented here and further data from accelerometers and strap sensors were recorded during these human trials. These data, coupled with the results on discomfort, decrement in timed performance, MVO_2 costs, shoulder and lumbar reaction forces reported in this current document form the initial required input data set with independent benchmarking for the further development of the DBM.

   It is recommended that accelerometer and strap force data be analyzed to assist with validation of the DBM. It is also recommended that the LC Simulator be used to develop the ability to determine body lean angles across a range of gait. The selected range of lean angles and gait will be based on the range of these parameters recorded during the human trials.

5. The portable system was used in this research study as well. With its capability, it is possible to use the accelerometers to determine body lean angles during standing and walking. This information, as well as the reaction forces on the shoulders and waist can be calculated and output if the biomechanical model is developed with these outcomes in mind. It is expected that the accelerometers, once validated (next phase of the portable system contract) can also be used to estimate the energy demand on the person as well. Hence, in subsequent field trials, recorded shoulder and lumbar reaction forces can be directly linked to subjective comments.

   It is recommended that the dynamic biomechanical model be developed to make use of the portable system data to provide direct feedback on shoulder and lumbar reaction forces as well as calculate estimates of task energy demands.

   It is also recommended that soldiers be asked for their subjective opinions about discomfort so the relationship between subjective opinions and objective discomfort scores can be described and quantified mathematically. This information will serve as an additional check on the tissue tolerance limits and discomfort estimates used in the DBM.

8. Reference List

Åstrand, P.O. and Rodall, K. Textbook of Work Physiology: Physiological Bases of Exercise. McGraw-Hill, Philadelphia, 1990.

Ayoub, M.M., Mital, A., Bakken, M.B., Asfour, S.S. and Bethea, N.J. (1980). Development of Strength and capacity norms for manual materials handling activities: the state of the art. *Human Factors* 22(3) 271-283.

Ayoub, M.M. (1982) Control of Manual Lifting Hazards: Job Redesign. *Journal of Occupational Medicine*, 24(9), 668-676.

Borghols, E.A.M., Dresen, M.H.W. and Hollander, A.P. (1978) Influence of heavy weight carrying on the cardiorespiratory system during exercise. *European Journal of Applied Physiology*, 38:161-169.

Bryant, J.T., Stevenson, J.M., Reid, S.A., Doan, J.B. and Rigby, A. SECTION D: Development of Acceptance Criteria for Physical Tests of Load Carriage Systems. Research and Development of an Advanced Personal Load Carriage System (Phase II and III). Contract # W7711-5-7273/001-TOS (27pgs), 1997g.

Bryant, J.T., Doan, J., Stevenson, J.M. and Pelot, R.P. Validation of objective based measures and development of a performance based ranking method for load carriage systems. Proceedings of the RTO – NATO Specialist Meeting, 15;1-12, 2001.

Casaburi, R., Storer, T.W., Ben-Dov, I. and Wasserman, K. (1987) Effect of endurance training on possible determinants of VO_2 during heavy exercise. *European Journal of Applied Physiology*, 62:199-207.

Doan, J.E., Reid, S.A., Stevenson, J.M., Bryant, J.T., Morin, E. and Pelot, R.P. SECTION D: Computer Database: Summary and Correlation of Load Carriage System Assessments. Research and Development of an Advanced Personal Load Carriage System (Phase IV). PWGSC Contract # W7711-7-7420/A (36 pgs), 1998.

Frykman, P.N., Harman, E.A. and Pandolf, C.E. Correlates of obstacle course performance among female soldiers carrying two different loads. Proceedings of the RTO – NATO Specialist Meeting, 9:1-9, 2001.

Garg, A. and Saxena, U. (1979) Effects of lifting frequency and technique on physical fatigue with special reference to psychophysical methodology and metabolic rate. *American Industrial Hygiene Association Journal*, 40:894-903.

Hagberg, J.M., Mullin, J.P. and Nagle, F.L. (1978) Oxygen consumption during constant-load exercise. *European Journal of Applied Physiology*, 45:381-384.

Haisman, M.F. (1988) Determinants of load carrying capability. *Applied Ergonomics,* 19(2) 111-121.

Harman, A.E., Han, K.H. and Frykman, P. Load-speed interaction effects on the biomechanics of backpack load carriage. Proceedings of the RTO – NATO Specialist Meeting, 5: 1-15, 2001.

Johnson, R.C., Pelot, R.P., Doan J.B. and Stevenson, J.M. The effect of load position on biomechanical and physiological measures during a short duration march. Proceedings of the RTO – NATO Specialist Meeting, 4;1-6, 2001.

Kalis, J.K., Freund, B.J., Joyner, M.J., Jilka, S.M., Nittolo, J. and Wilmore, J.H. (1988) Effect of ß-blockade on the drift in O_2 consumption during prolonged exercise. *European Journal of Applied Physiology*, 64:753-758.

Kinoshita, H. (1985). Effects of different load carriage systems on selected biomechanical parameters describing walking gait. *Ergonomics* 28(9): 1347-1362.

Knapik, J., Harman, E. and Reynolds, K. (1996) Load carriage using packs: A review of physiological, biomechanical and medical aspects. *Applied Ergonomics*, 27(3):207-216.

Knapik J. Physiological, biomechanical and medical aspects of soldier load carriage. 2001. Proceedings of the RTO – NATO Specialist Meeting, KN1;1-20, 2001.

Léger, L. and Boucher, R. (1980) An indirect continuous running multistage field test: The Université de Montréal track test. *Canadian Journal of Applied Sports Science*, 5(2): 77-84.

Loehr, James E. *Mental Toughness Training for Sports: Achieving Athletic Excellence.* The Stephen Greene Press, Lexington Massachusetts, 1986.

MacNeil, S. Biomechanical Assessment of Strap Forces and Pressures During Load Carriage. Masters Thesis, Queen's University, Kingston, Canada, 1996.

Martin, P.E. and Nelson, R.C. (1986) The effect of carried loads on the walking patterns of men and women. *Ergonomics,* 29(10):1191-1202.

McGaig, R.H. and Gooderson, C.Y. (1986) Ergonomics and physiological aspects of military operations in a cold wet climate. *Ergonomics*, 29(7):849-857.

Michael, E.D., Hutton, K.E., Horvarth, S.M. (1961) Cardiorespiratory responses during prolonged exercise. *European Journal of Applied Physiology*, 16:997-1000.

Mital, A. (1983) The psychological approach in manual lifting – a verification study. *Human Factors*, 23(10):485-491.

Mital, A. (1984) Maximum weights of lift acceptable to male and female industrial workers for extended work shifts. *Ergonomics,* 24(11):1115-1126.

Myles, W.S. and Saunders, P.L. (1979) The physiological cost of carrying light and heavy loads. *European Journal of Applied Physiology,* 42:125-131.

Pandolf, C.E., Harman, E.A., Frykman, P.N., Patton, J.F., Mello, R.P. and Nindl, B.C. Proceedings of the RTO – NATO Specialist Meeting, 2: 1-9, 2001.

Patton, J.F., Kaszuba, J., Mello, R.P. and Reynolds, K.L. (1991) Physiological responses to prolonged treadmill walking with external loads. *European Journal of Applied Physiology,* 63:89-93.

Pelot, R.P., Rigby, A., Bryant, J.T., Stevenson, J.M. SECTION C: Phase II of a Biomechanical Model for Load Carriage Assessment. Research and Development of an Advanced Personal Load Carriage System (Phase IV). PWGSC Contract # W7711-7-7420/A (45 pgs), 1998.

Pierrynowski, M.R., Norman, R.W. and Winter, D.A. (1981) Metabolic measures to ascertain the optimal load to be carried by man. *Ergonomics*, 24:393-399.

Polycn, A.M., Bensel, C.K., Harman, E.A. and Obusek, J.P. Effect of load weight: Summary Analysis of Maximal Performance, Physiological and Biomechanical Results from four studies of load carriage systems. Proceedings of the RTO – NATO Specialist Meeting, 7: 1-11, 2001.

Saltin, B. and Stenberg, J. (1964) Circulatory responses to prolonged severe exercise. *European Journal of Applied Physiology,* 19:833-838.

Sawka, M.N., Knowlton, R.G. and Critz, J.B. (1979) Thermal and circulatory responses to repeated bouts of prolonged running. *Medicine and Science in Sports*, 11:177-180.

Snook, S.H. (1978) The design of manual handling task. *Ergonomics*, 21:963-985.

Snook, S.H. and Cirello, V.M. (1974) Maximum weights and workloads acceptable to female workers. *Journal of Occupational Medicine.* 16(8) 527-534.

Snook, S.H. and Cirello, V.M. (1991) The design of manual handling tasks: revised tables of maximum acceptable weights and forces. *Ergonomics*, 34:1197-1213.

Snook, S.H., Irvine, C.H. and Bass, S.F. (1970) Maximum weights and workloads acceptable to male industrial workers. *Journal of Occupational Medicine.* 31:579-586.

Soule, R.G., Pandolf, K.B. and Goldman, R.F. Energy expenditure of heavy load carriage. *Ergonomics* 21:373-381, 1978.

Soule, R.G. and Goldman, R.F. (1972) Terrain coefficients for energy cost prediction. *Journal of Applied Physiology* 32(5):706-708.
Stevens, S.S. (1960) The psychophysics of sensory function. *American Scientist.* 48:226-253.

Stevenson, J.M., Bryant, J.T., DePencier, R.P., Pelot, R.P. and Reid, J.G. Research and Development of an Advanced Personal Load Carriage System: Section A, B, C (Phase I). DSS Contract # W7711-4-7225/01-XSE 29 (350 pgs), 1995.

Stevenson, J.M., Bryant, J.T., Reid, S.A. and Pelot, R.P. Validation of the Load Carriage Simulator: Research and Development of an Advanced Personal Load Carriage System: Section D (Phase 1). DSS Contract # W7711-4-7225/01-XSE (44 pgs), 1996.

Stevenson, J.M., Bryant, J.T., Morin, E.L., Pelot, R.P., Reid, S.A. and Doan, J.D. Research and Development of an Advanced Personal Load Carriage System: Phase IV. PWGCS Contract # W7711-7-7420/A (320 pages), 1998.

Stevenson, J.M., Reid, S.A., Bryant J.T., Hadcock L.J. and Morin E.L. Development of a dynamic biomechanical model for load carriage: Phase 1. PWGSC # W7711-0-7632-01 (64 pages), 2000.

Stevenson, J.M., Reid, S.A., Bryant J.T., Hadcock L.J. and Morin E.L. Development of a dynamic biomechanical model for load carriage: Phase 2. PWGSC # W7711-0-7632-02 (50 pages), 2001.

Stevenson, J.M., Bryant, J.T., Reid, S.A., Pelot, R.P. and Morin, E.L. Development of the Canadian Integrated Load Carriage System using Objective Measures. Proceedings of the RTO – NATO Specialist Meeting, 21;1-11, 2001.

Appendix A

Informed Consent Form

Appendix B

Raw data from the Marching Orders Tasks

(Contained in Excel Spreadsheet called
Marching Orders Data Books JMS Final
Dated June 27, 2002)

Appendix C

Raw data from the Standing Posture for the Biomechanical Model

(Contained in Excel Spreadsheet called
Biomechanical Model – Static Final
Dated June 27, 2002)

Appendix D

Mental Toughness Questionnaire

By James E Loehr (1986)

(Contained in WORD File called
Motivation Questionnaire
Dated December 3, 2001)

Queen's University

Performance Inventory

This series of questions is designed for athletes as part of goal setting for optimum sports performance. We have **NOT** modified it to suit the military situation. Please circle the number that you believe best describes your personal characteristics in a competitive military situation. These results are confidential to the researchers only, and we will provide feedback after your last session at Queen's. No Military personnel will ever see the answers to this questionnaire.

1. I see myself as more of a loser than a winner in competition.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

2. I get angry and frustrated during competition.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

3. I become distracted and lose my focus during competition.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

4. Before competition, I picture myself performing perfectly.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

5. I am highly motivated to play my best.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

6. I can keep strong positive emotion flowing during competition.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

7. I am a positive thinker during competition.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

8. I believe in myself as a player.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

9. I get nervous or afraid in competition.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

10. It seems my mind starts racing 100 mph during critical moments of competition.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

11. I mentally practice my physical skills.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

12. The goals I've set for myself as a player keep me working hard

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

13. I am able to enjoy competition even when I face lots of difficult problems.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

14. My self-talk during competition is negative.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

15. I lose my confidence very quickly.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

16. Mistakes get me feeling and thinking negatively.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

17. I can clear interfering emotion quickly and regain my focus.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

18. Thinking in pictures about my sport comes easy for me.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

19. I don't have to be pushed to play or practice hard. I am my own best igniter.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

20. I tend to get emotionally flat when things turn against me during play.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

21. I give 100 percent effort during play, no matter what.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

22. I can perform toward the upper range of my talent and skill.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

23. My muscles become overly tight during competition.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

24. I get spacey during competition.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

25. I visualize working through tough situations prior to competition.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

26. I'm willing to give whatever it takes to reach my full potential as a player.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

27. I practice with high positive intensity.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

28. I can change negative moods into positive ones by controlling my thinking.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

29. I'm a mentally tough competitor.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

30. Uncontrollable events like the wind, cheating opponents, and bad

referees get me very upset.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

1

31. I find myself thinking of past mistakes or missed opportunities as I play.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

32. I use images during play that help me perform better.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

33. I get bored and burned out.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

34. I get challenged and inspired in tough situations.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

35. My coaches would say I have a good attitude.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

36. I project the outward image of a confident fighter.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

37. I can remain calm during competition when confused by problems.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

38. My concentration is easily broken.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

39. When I visualize myself playing, I can see and feel things vividly.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

40. I wake up in the morning and am really excited about playing and practicing.

1	2	3	4	5

Almost Always	Often	Sometimes	Seldom	Almost Never

41. Playing this sport gives me a genuine sense of joy and fulfillment.

1	2	3	4	5
Almost Always	Often	Sometimes	Seldom	Almost Never

Scoring of Answers to Performance Questionnaire
Military Study – December 2001

Self Confidence	Negative Energy	Attention Control	Visual & Imaginary Control	Motivational Level	Positive Energy	Attitude Control
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	32	33	34	35

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(U) This work was undertaken in support of the research thrust “Development of a Dynamic Biomechanical Load Carriage Model”. The report describes human response characteristics, both objective and subjective, to a mobility circuit. The goals of the study were to examine the relationships among aerobic demand, performance time and load as well as the relationships between posture, shoulder and lumbar reaction forces and load. Eleven subjects volunteered for three aspects of the study: a maximal aerobic capacity test and two test days for each load carriage system, Pack C and Pack D. During the testing, subjects were instrumented with a heart rate monitor, accelerometers on the person and in the pack, and strap force sensors on the lower shoulder strap and on the waist belt. The circuit was completed five times in Battle Order of 5.5 kg, followed by randomized rucksack loads of 15.7 kg, 25.5 kg and 34.3 kg, as well as a self−selected maximal load. Subjects were asked to assume a pace they could sustain all day, given the load they were asked to carry. The circuit consisted of a number of marching and mobility tasks and was timed for all components of the circuit. Statistics were done using two− and three−way repeated measures ANOVAs. There were significant differences in timed performance and load (p=0.001) and between aerobic demand and load (p=0.008) but not between packs. This relationship held true for both laps and tasks. This resulted in a decrease in performance time of 19% and an increase in aerobic demand of 21% for the heaviest load compared to Battle Order. There was a significant increase in upper body and head lean angles and shoulder and lumbar reaction forces often between packs and always between loads. Posture changed by as much as 40% of the light weight’s postural lean angles with shoulder and hip reaction forces being 120% to 150% greater than the light load with the lumbar forces exceeding recommended limits. Subjective responses to various circuit demands and discomfort were also summarized. Future dynamic biomechanical modelling work should be directed toward integrating the model with the portable measurement system and so that the relationships between aerobic demand, shoulder and lumbar reaction forces and subjective discomfort can be determined for longer military exercises under variable loads.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) Load carriage; Dynamic Biomechanical Model; Mobility Circuit; Task Performance; Maximal Aerobic Fitness Test; Load Control Circuit; Mobility Task