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Platforms Sciences Laboratory

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ABSTRACT

This report details the tactility and dexterity of four different glove types, including the Australian in-service NBC butyl rubber glove and Nomex® flying glove for standardised (Purdue pegboard) and operational (weapon asembly/disassembly) tasks. The Nomex® flying glove was included for comparative purposes despite offering no NBC protection . Two commercially available chemically protective gloves (the Canadian NBC butyl rubber glove, Ansell TNT® nitrile glove) were also assessed. Twenty-four healthy male subjects participated in the study. Subjects completed two questionnaires, one on the priority of glove functions and the second on glove specific fit and fuctionality. Subjects completed either the weapon assembly/disassembly task or the Purdue pegboard task. The results from both these tasks were consistent for all gloves and in agreement with the reponses recorded on the questionnaires. The Ansell TNT glove tended to provide the best dexterity scores followed by the Nomex flying, Canadian butyl and Australian butyl gloves. The Ansell TNT glove tended to be the most tactile glove followed by the Candian Butyl, Nomex flying and Australian butyl. Subjects felt their performance in the Australian Butly rubber glove could be enhanced through training and by adopting seamless liners similar to those used in the Canadian system. Overall subjects preferred single layered, seamless gloves that had a low impact on task-dependant dexterity and tactility. Typically subjects felt that if the Nomex flying glove offered NBC protection and had the seam removed on the index finger it would make an ideal NBC glove. The outcomes of this study provide a scientific basis from which a requirements document for a new NBC glove could be generated. It is intended that the most favourable features of a glove identified during this study will be used in future ADF NBC glove designs.

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A Dexterity and Tactility Evaluation of the Australian Nuclear Biological Chemical (NBC) Glove

Executive Summary

This report details the tactility and dexterity of four different glove types, including the Australian in-service NBC butyl rubber glove. The Nomex® flying glove was included in the study for comparitive purposes despite offering no NBC protection as it is highly regarded within the ADF. Two other commercially available chemically protective gloves (the Canadian NBC butyl rubber glove, Ansell TNT® nitrile glove) were also assessed.

Twenty-four healthy male subjects participated in the study completing questionnaires and completing either a weapon assembly/disassembly task or the Purdue pegboard task. The Purdue pegboard task requires subjects to pick up small pins, collars and washers and assemble them on a board. The tactility of subjects completing the Purdue pegboard task was also assessed.

The results of the weapon assembly/disassembly and Purdue pegboard tasks were consistent for all gloves and in agreement with the reponses recorded on the questionnaires. The Ansell TNT glove tended to record the best dexterity scores followed by the Nomex flying, Canadian butyl and Australian butyl gloves. The Ansell TNT glove tended to be the most tactile glove followed by the Candian Butyl, Nomex flying and Australian butyl.

Subjects felt their performance in the Australian Butly rubber glove could be enhanced through training and by adopting seamless liners, similar to those used in the Canadian system. Overall subjects preferred single layered, seamless gloves that had little impact on the tasks they were performing. Typically subjects felt that if the Nomex flying glove offered NBC protection and had the seam removed on the index finger it would make an ideal NBC glove.

The methods and results reported in the document form a basis on which the perfomance of new NBC gloves can be scientifically compared in terms of tactility and dexterity to the current Australain NBC butyl rubber glove. It is also intended that the outcomes of this study will form the scientific basis from which a requirements document for a new NBC glove can be generated.

Contents

1. Introduction

The traditional concept of potential chemical and biological battlefields has changed. Protective equipment originally designed for a specific purpose may now be applied to new and alternative roles. In a Nuclear Biological Chemical (NBC) contaminated environment there are several conditions where gloves can hinder task performance. Performing operational tasks while wearing gloves can prolong work times leading to frustration and decreased capability. Tasks normally defined as simple and straight forward when not wearing gloves may become complex and difficult when protective gloves are worn.

The current NBC protective glove used by the Australian Defence Force (ADF) is manufactured from butyl rubber and is available in a range of sizes: X-small, Small, Medium, Large, and X-Large. The glove is nominally 0.635 mm (0.025 inch) thick and meets current protection requirements. Typically with increasing thickness, gloves offer greater protection and durability [1], however tactility[1] and dexterity[2] decreases [2-7]. When tasks involving fine motor skills are important requirements, a balance between appropriate protection, durability, tactility and dexterity is necessary [8].

This report details the tactility and dexterity of the Australian in-service NBC butyl rubber glove and the Nomex® flying glove for standardised and operational tasks. Although offering no NBC protection, the Nomex® flying glove was included for comparison purposes as it is highly regarded by members of the ADF for its comfort and functionality. Two commercially available chemically protective gloves (the Canadian NBC butyl rubber glove, Ansell TNT® nitrile glove) were also assessed. The results from this study provide information related to glove preferences when used to perform tasks requiring tactility and dexterity. The outcomes will also provide a scientific basis from which a new NBC glove requirements document can be generated.

2. Experimental

2.1 Subjects

Following an initial briefing on the purpose and demands of the trial (Appendix A-B) twenty-four healthy male subjects volunteered. The subjects consisted of two distinct groups, 12 volunteer soldiers from the ADF (5/6 Royal Victorian Regiment, D Company) and a further 12 volunteers from the Defence Science Technology Organisation (DSTO, Scientists). All volunteers were given adequate familiarisation of the required tasks (practice trials) prior to the assessment trials to minimise any effect of training. The two groups of volunteers performed different tasks. The ADF soldiers

[1] Tactility: a measure of the sense of touch.

[2] Dexterity: the ability to perform manipulative tasks.

performed operational tasks (weapon assembly/disassembly) and the DSTO staff undertook standardised tasks (commercially available tactility/dexterity assessment tests). The allocation of tasks to a specific group (ADF or DSTO) with no crossover was found to be the most efficient way of examining the relative performance of various protective gloves (independent of operational setting).

2.2 Gloves

The following five gloves were assessed:

- ADF NBC butyl rubber gloves with cotton liners manufactured by Norton Company. Sizes: Small, Medium, Large, and X-Large.
- ADF Nomex® flying glove manufactured by Transaero INC. Sizes: 7, 8, 9, 10 and 11.
- Canadian NBC butyl rubber gloves with cotton liners manufactured by Acton® International INC, Acton Vale, Canada. Sizes: Medium-Medium, Large-Narrow, Large, X-large-Narrow, and X-Large.
- Ansell Touch N Tuff™, disposable nitrile gloves, Thin Nitrile Technology® manufactured by Ansell Protective Products, Thailand. Sizes: Small, Medium, Large, and X-Large.
- Negative control: A large air permeable glove with butyl rubber patches on the fingers and palms was included as a poorly fitted glove.

All subjects selected and fitted their own gloves for "best fit" by a process of trial and error. The best possible fit (positive control) was illustrated by conducting the tasks without gloves (no gloves). A large air permeable glove was included in the study to illustrate the performance of an ill-fitted glove (negative control). No subjects were able to find a suitably sized negative control glove.

2.3 Experimental Procedures

DSTO and ADF trials were conducted in a well-lit laboratory or classroom. The ADF trial was conducted over two nights using two groups of six subjects. The weapon assembly/disassembly task was conducted under the direction of a senior officer using blank ammunition. Subject's age, dominant hand, hand length and hand circumference according to the Australian and New Zealand Standard [9, 10] was recorded after subjects completed the initial questionnaire (experimental task 1, given in section 2.4.1, below).

Experimental tasks (listed in section 2.4) were repeated by each subject, wearing each of the five types of gloves and also with no gloves. The DSTO group completed experimental tasks 1, and 3-5, whilst the ADF group completed tasks 1, 2, and 5 in that order. Each glove was tested in sequential order (with 5 minutes rest between each glove tested and 15 minutes rest after 3 gloves had been tested) for each subject. Each subject's starting glove was delivered in a fully balanced order across all subjects. The time taken by each group to complete all tasks was less than 3 hours.

2.4 Experimental Tasks

2.4.1 Task 1: Priority Ranking of Glove Functions Questionnaire

The questionnaire (Appendix C) aims to identify the importance that subjects place on a range of glove functions. The questionnaire was scored by subjects' responses to the questions on a Likert scale from 0-9, with 9 being most important and 0 being the least important. The questionnaire was completed once, prior to the dexterity or tactility testing.

2.4.2 Task 2: Weapon Assembly/Disassembly

The purpose of this task was to measure the decrement in a soldier's ability to assemble and disassemble a weapon whilst wearing gloves. The test was scored by the time taken to completely disassemble and then re-assemble the standard ADF issue Steyr rifle (average of three fastest trials out of a total of four). The subjects loaded blank ammunition into the speed loaders and magazines, and any difficulties in performing this task whilst wearing gloves/no gloves were reported on the functionality questionnaire.

2.4.3 Task 3: Purdue Peg Board Test Model 32020 (Layfette Instrument Company, USA)

This test measured the gross movements of hands, fingers, arms, and fingertip dexterity in assembly tasks. The pegboard consists of pins, collars and washers. The four standard timed tests were:

- Right hand, pins only, 30 sec
- Left hand, pins only, 30 sec
- Both hands, pins only, 30 sec
- Both hands assembly, pins, collars and washers, 1 min

The test was conducted according to the manufacturers' requirements [11] with the slight variation of completing the right hand tasks before proceeding to the left hand, both hands, and assembly task respectively. The test was scored by counting the number of pins (or assemblies) placed in the board within the allocated time, and the average was taken for the three best scores out of a total of four trials. This test was repeated for all glove types and with no gloves.

2.4.4 Task 4: Touch Test™ Sensory Evaluators (North Coast Medical Inc., USA)

This test measured the tactile responses for the thumb, index and middle finger of each hand. This test was scored by rating subjects responses to the thickness of the smallest monofilament they could feel (either 2.83 (target force = 0.07 N), 3.61 (0.4 N), 4.31 (2 N), 4.56 (4 N) or 6.65 (300 N)). The test was administered in accordance to the manufacturers requirements [12]. In this test the thinnest monofilament was pushed against the appropriate fingertip of the subject until the monofilament bent, which corresponded to the maximum force that could be applied. This process was repeated a maximum of three times (except for filaments >4.31 which were only applied once) before proceeding to a thicker monofilament. The test was scored by the thinnest monofilament that elicited a response from the subject. This test was repeated for all glove types and no gloves.

2.4.5 Task 5: Glove Fit & Functionality Questionnaire

This questionnaire (Appendix D) identified how the glove fitted, how users perceived their ability to perform their duties whilst wearing them, and how easy the gloves were to don and doff [13]. The questionnaire was answered by each subject for each glove, including no glove, and subjects' responses were rated as either: Strongly Agree, Agree, No Preference, Disagree or Strongly Disagree.

The questionnaire contained two negative statements, "the gloves are not dextrous enough" and "the gloves are not tactile enough" to ensure subjects correctly read each item. To obtain an overall glove index (high score most preferred, low score least preferred) the responses to these two questions were inverted to provide the positive response, i.e. a Strongly Agree response to "the gloves are not dextrous enough" became a Strongly Disagree response to the positive statement "the gloves are dextrous". The final four items on the questionnaire were similarly negative statements and hence these results were also inverted. Consequently when the responses of the questionnaire were summed, the most favourable glove had the highest score on the 'glove index'.

2.5 Glove Thickness

Glove thickness was measured using a micrometer (TESA, 0-25 mm, Switzerland). Three gloves of each type were measured at the index finger with care taken to avoid seams and folds. Glove thickness of the dual glove systems was measured by summing the thickness of the liner with that of the outer glove. The impact of seams was calculated from the above measurements assuming the worst possible overlap as follows: 1) The Australian butyl glove liner seam (two layers) could be folded over underneath the fingertip, thus equating to a maximum of three layers of the liner plus the thickness of the butyl rubber glove; 2) Similarly the negative control glove seam can fold over equating to a maximum of three layers; 3) The Nomex® flying glove seam can fold over equating two layers of leather and one layer of Nomex®.

2.6 Statistics

One-way repeated ANOVAs were performed to examine effects of the different gloves on each dependent variable (Perdue pegboard tasks: left hand, right hand, both hands and assembly task times; weapon assembly/disassembly time). Differences were isolated post hoc using Tukeys HSD at $p<0.05$. Subject's mean (thumb, index and middle finger) result for the Touch Test was calculated for both the left and right hands. The pooled mean, maximum, and minimum (left and right hand) results for all subjects was then calculated and presented descriptively. A Glove Index (GI) was created for each glove by adding scores from each item within the glove questionnaire, i.e. the higher the GI, the more preferable the glove. Correspondence analysis was performed to clearly present glove preference and relative similarities between gloves (closeness in scores). All analyses were separated by user type (military/civilian) since it is anticipated that each group will have different subjective responses to each glove depending on experience. All data is presented as means ± 95% confidence intervals, unless specified otherwise.

3. Results

3.1 General

Soldiers mean age was 21.25 ± 3.3 years, left hand length 18.92 ± 0.67 cm, left hand circumference 21.93 ± 0.95 cm, right hand length 18.89 ± 0.82 cm, right hand circumference 22.2 ± 0.74 cm. Ten of the 12 soldiers reported their right hand as being dominant and the remaining two their left hand. The scientists mean age was 40.08 ± 11.7 years, left hand length 19.88 ± 0.84 cm, left hand circumference 22.07 ± 1.76 cm, right hand length 19.91 ± 1.06 cm, right hand circumference 22.44 ± 1.76 cm. All twelve scientists reported their right hand as being dominant. No subjects reported themselves as being ambidextrous. All subjects were able to find an appropriately sized glove except for the negative control glove, which was intentionally too large for all subjects.

3.2 Priority of Glove Functions

Subjects responses to the priority function of gloves were pooled and ranked (see Table 1) as there were no prior task dependent influences (i.e. before commencing the weapon assembly/disassembly or Purdue pegboard tasks) on their decision-making. The responses provide a clear indication of what characteristics an ideal glove should include. In terms of glove function, subjects rated glove fit as having the highest priority, followed by dexterity, grip, chemical protection and tactility. Chemical protection was not rated the highest priority, although this study was centred on testing chemical protective gloves. Surprisingly, glove comfort was not ranked in the top five priorities although glove fit (highest ranked function) is a function of comfort. This may be a result of anticipated use, for example users may feel that the glove is only going to be worn for a defined period of time so their tolerance for discomfort is higher.

Table 1 Ranked Priorities of Glove Functions

Rank Priority	Mean	SD	Function
1	8.1	1.0	Fit
2	7.7	1.1	Dexterity
3	7.7	1.5	Grip
4	7.4	1.8	Chemical Protection
5	7.3	1.7	Tactility
6	7.2	1.9	Comfort
7	6.9	1.9	Durability
8	6.7	2.2	Integration
9	6.6	1.7	Sweat Removal
10	6.4	1.9	Ease of Don/Doff
11	6.3	2.3	Thermal Insulation
12	6.2	2.6	Bulk
13	5.1	2.7	Weight
14	4.4	2.8	Odour
15	4.0	2.6	Shelf Life
16	3.9	3.0	Cost

The subjects placed a low priority on the bulk and weight of gloves, and accorded a higher priority on the fit and functionality. As expected the cost of the gloves and their shelf life were of little importance to the user. Subjects expected a high quality glove and did not feel the cost of the glove should be of concern. However from a military logistical point of view, cost, shelf life, and durability are major influences in selecting a glove. It was encouraging to observe that integration was an intermediate priority as it is well accepted that this is an important consideration for operational effectiveness.

3.3 Weapon Assembly/Disassembly

The mean time taken to completely disassemble and reassemble a Steyr whilst wearing gloves is presented in Figure 1. As expected wearing no gloves recorded the lowest mean time, although this was not significantly different ($p>0.05$) to correctly fitted Ansell TNT® gloves, Nomex® flying gloves, or Canadian butyl rubber gloves. The Australian butyl rubber glove and negative control glove recorded significantly (both $p<0.05$) slower times than wearing no gloves.

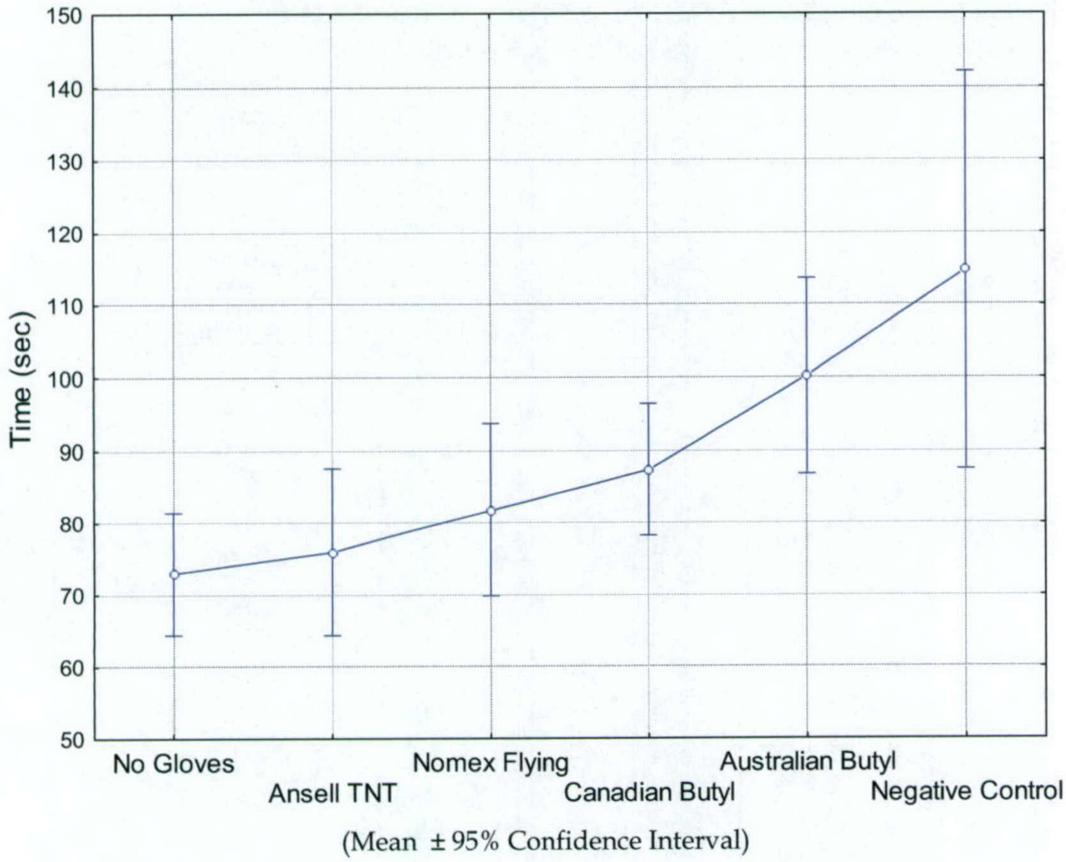


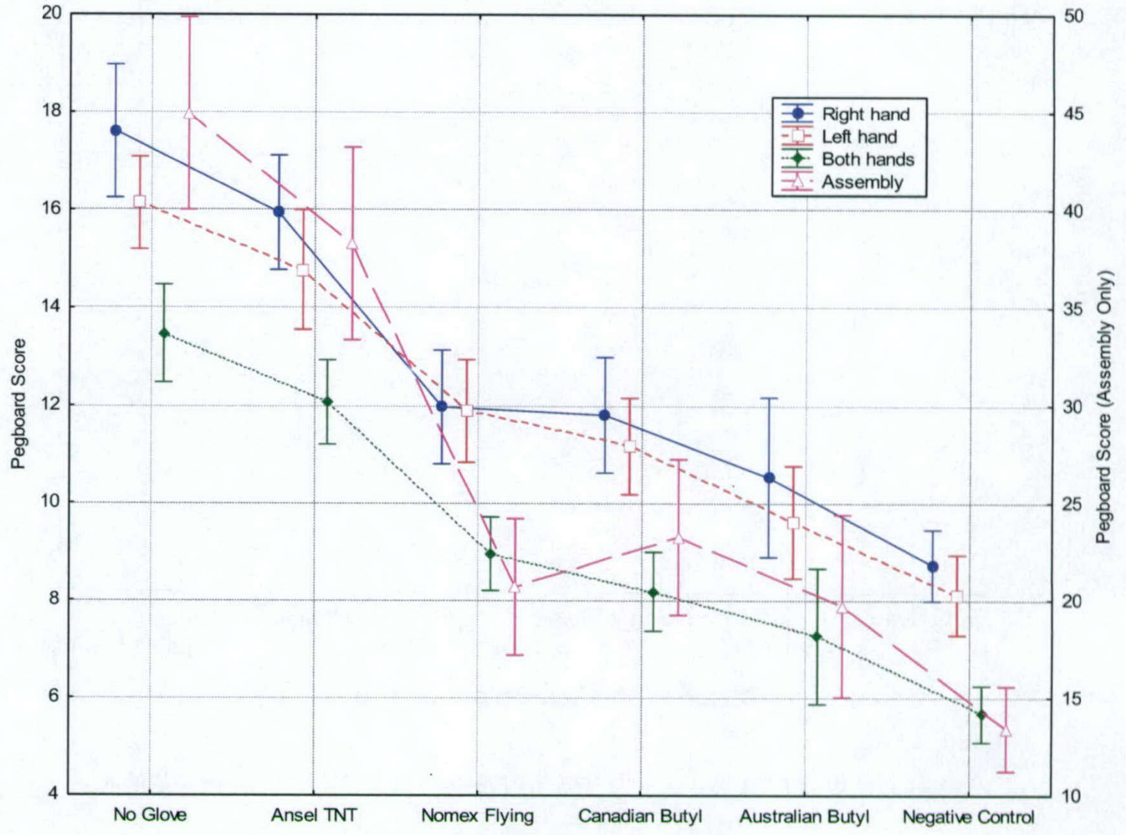
Figure 1: The time recorded to perform the weapon assembly/disassembly task

Overall no gloves (positive control) tended to record the fastest times mean followed by Ansell TNT® , Nomex® flying, Canadian butyl, Australian butyl and finally the negative control glove. The poor result for the negative control glove was clearly a function of the inadequate sizing. The Canadian butyl rubber glove with pleating at the knuckles tended to give quicker times than the Australian butyl glove and this was reflected in their slightly more favourable responses given in the glove specific questionnaire (See Section 3.6).

3.4 Purdue pegboard

The Purdue pegboard scores for right hand, left hand, both hands and the assembly task followed the same trend for all gloves, except for the assembly task where the Canadian butyl glove scored better than the Nomex® flying glove (Figure 2). This result may have been a function of the seam on the index finger of the Nomex® flying glove adversely affecting scores particularly when picking up the collar used in the assembly task. Typically no gloves and Ansell TNT® gloves were significantly better (all, $p<0.05$) than all other gloves in the Purdue pegboard tasks. As expected the negative control glove performed significantly poorer (all, $p<0.05$) than all other gloves (except

Australian butyl, p>0.05), and the Nomex® flying, Canadian butyl and Australian butyl rubber gloves were similar (all, p>0.05) to each other.



(Mean ± 95% Confidence Interval)

Figure 2: Purdue pegboard scores

In summary, the best mean scores were achieved by No gloves followed by Ansell TNT®, Nomex® flying, Canadian butyl, Australian butyl and then the negative control gloves. The Purdue pegboard and weapon assembly/disassembly tasks have demonstrated similar trends across gloves used in this study independent of user type.

3.5 Tactility

The tactility of each glove is presented in Figure 3. A low mean target force when applied to subjects' fingertips to elicit detection indicates a more tactile glove compared to a higher target force. As expected, the Ansell TNT® glove performed extremely well in terms of tactility and could not be distinguished from wearing no gloves. The Canadian butyl gloves tended to provide greater tactility than the Nomex®

flying gloves even though it did not perform as well during the weapon assembly/disassembly and the Purdue pegboards tasks. The poorest tactility was observed for the negative control glove, with the Australian butyl glove performing marginally better.

As the mean target force required to elicit a response increased, so did the variability. A possible reason for this is that during the assessment, the gloves occasionally were not in direct contact with the skin, creating air gaps. Consequently some subjects responded to the glove being pushed against the skin in a different position rather than under the filament (under-estimated force). Other subjects did not respond until a greater force (over-estimated force) was applied which was necessary to overcome the air gap due to tensile strength/elasticity of the glove. Nevertheless, if this is a true reflection of fitting problems with gloves in the operational setting then these tactility comparisons indicate potential problems with the poorer fitting gloves.

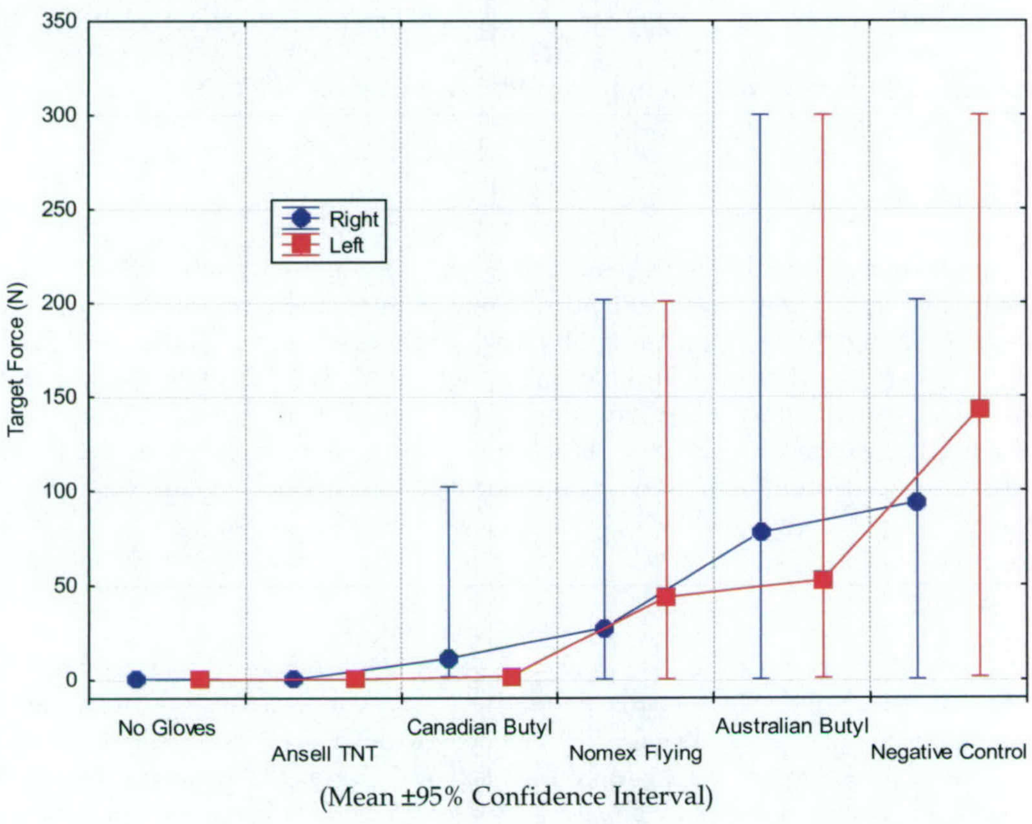


Figure 3 Touch test tactility rating

Typically this variability was observed only with the largest Touch Test sensory evaluator, which applied a target force of 300 N. Unfortunately there was a large gap in the 5-piece monofilaments Touch Test sensory evaluator kit, i.e. 4 filaments had a target force below 5 N and the 5th being 300 N. To provide a more accurate indication of tactility and its associated variability, the gloves needed to be in direct contact with the skin and more monofilaments needed to be tested in the range of 4-300 N.

3.6 Glove Fit and Functionality

3.6.1 Finger, Knuckle and Wrist Fit

Subjects either had no preference or agreed that all gloves except the negative control fitted them well at the fingertips, thumb, knuckles, and wrists. The negative control glove was found to be significantly poorer fitting (all $p<0.05$) than all other gloves. As expected, Ansell TNT® gloves tended to be the preferred glove in terms of finger and thumb fit, and both Ansell TNT® and Nomex® flying gloves tended to be most preferred in terms of knuckle and wrist fit.

3.6.2 Training

Subjects generally agreed that training would improve their ability to perform a task independently of glove type.

3.6.3 Durability

Subjects performing the Purdue pegboard task generally agreed that all gloves except the Ansell TNT® glove were sufficiently durable to perform the task. On the other hand subjects completing the weapon assembly/disassembly task generally agreed that all of the gloves were sufficiently durable, including the Ansell TNT® glove (rated the highest). This result is surprising considering the Ansell TNT® glove actually broke more during this weapon assembly/disassembly task when compared to the Purdue pegboard task, indicating a possible misunderstanding of this question by the some users.

3.6.4 Tactility

Subjects completing the weapon assembly/disassembly task generally were undecided as to whether the gloves were tactile enough or not. Whereas those performing the Purdue pegboard task generally agreed that all gloves were not tactile enough to perform the required tasks except for the Ansell TNT® glove. Not surprisingly, the ranking of each gloves' tactility by subjects completing the Purdue pegboard task was in agreement with the tactility results presented in Section 3.5.

Subjects performing operational type tasks (weapon assembly/disassembly) found the Nomex® flying glove to be sufficiently tactile, whereas those performing standardised type task (Purdue pegboard) found the glove to be inadequate. This observation emphasises the importance of glove-task integration (for example, the glove integrates well with Steyr requirements but not the fine motor requirements of a nuts and bolts assembly task).

3.6.5 Dexterity

Subjects completing the weapon assembly/disassembly task generally reported no preference to the glove dexterity question. In contrast, those completing the Purdue pegboard task rated the Ansell TNT® glove as having excellent dexterity and all other gloves were rated as poor. Similar to the tactility question above it appears the dexterity of the glove is adequate for some tasks but not others (i.e. task dependent).

3.6.6 Mission

Subjects generally felt that wearing the Ansell TNT® gloves would not affect their ability to complete a mission, whereas they had a neutral response for all other gloves except the negative control glove. Subjects felt the poorly fitting negative control glove would adversely affect their ability to complete the mission.

3.6.7 Donning and Doffing

The Australian butyl, Canadian butyl, and Ansell TNT® gloves were rated similarly in terms of donning with subjects indicating that they were neither difficult nor easy to don. This ambivalence is possibly due to the skin tight nature of the Ansell TNT® glove, and the Australian and Canadian double glove system (i.e. butyl gloves are worn over cotton liners) which, while not difficult to don, can be time consuming. The Australian butyl and Canadian butyl were rated as easy to doff whereas the skin-tight Ansell TNT® gloves were rated the hardest to doff. The single layer fabric gloves (Nomex® flying and negative control) were found to be easiest to don and doff.

3.6.8 Tightness

Subjects tended to agree that the Australian and Canadian butyl gloves were too tight, which may be a function of the double glove system. Subjects felt that the Nomex® flying and negative control gloves were not tight, which wasn't surprising considering that the Nomex® flying gloves are constructed from a knitted fabric and the negative control gloves were too large. Similarly subjects rated the Ansell TNT® gloves as not being tight (even though they were skin tight) which is most likely a reflection of the highly flexible/elastic thin nitrile material.

3.6.9 Sticky

Subjects reported that the fabric gloves (Nomex® flying and negative control) were the least sticky (as expected), whereas the polymer based gloves (Australian butyl, Canadian butyl and Ansell TNT®) were reported as neutral.

3.6.10 Integration with existing equipment

Subjects generally responded that the negative control gloves would poorly integrate with existing ADF equipment, which was expected for an ill-fitting glove with poor tactility and dexterity. The Australian butyl, Canadian butyl and Nomex® flying gloves were also thought to cause integration concerns and problems. Conversely, there did not appear to be integration issues associated with Ansell TNT® gloves, however the DSTO subjects suggested that the gloves may not be sufficiently durable (Section 3.6.3).

3.6.11 Weapon and Ammunition Handling

The Ansell TNT® glove was rated the best glove for assembling and disassembling the Steyr as well as loading and handling ammunition, followed by the Nomex® flying, Canadian butyl, and Australian butyl gloves. The poorly fitting negative control gloves caused the most difficulties when performing these tasks.

3.6.12 General Comments

Subjects felt the durability of the Ansell TNT® glove would be unsuitable for military operations. In fact the glove suffered puncture holes, in particular after inserting the firing pin into the firing mechanism of the Steyr. Both ADF and DSTO subjects commented on the lack of durability of the Ansell TNT® glove, which was contradicted in the questionnaire results from the ADF subjects (Section 3.6.3). The durability of the other gloves was not of concern to the subjects.

The most common complaint of the Nomex® flying glove was the tactility of the index finger because of a seam, sewn at the tip of the index finger, making it difficult for subjects to determine if they did or did not have something in their grip. This was noticeable in both tasks, but more obvious during the Purdue pegboard assembly task. The drop in performance of the Nomex® flying glove compared to the Ansell TNT® glove was more pronounced for tasks requiring fine motor skills (such as the Purdue pegboard tasks; ~44%, Figure 2), than the tasks which required gross motor skills of the weapon assembly/disassembly (~13%, Figure 1). This emphasises the task dependent nature of the relative performance of the different types of gloves.

The double glove systems (butyl rubber gloves worn over the cotton liners) used by the Australians and Canadians was not preferred over wearing a single glove such as the Nomex® flying glove. The Canadian knitted (no seams) cotton liners were preferred over the Australian sewn (seams) cotton liners. The subjects also expressed that the performance of the Australian butyl gloves could be improved by switching to knitted liners. In reference to the Canadian butyl rubber gloves, it was felt that the ribbing/pleating (which was used to provide extra room when the fingers are bent at the second and third joints from the finger tip) was generally too low (incorrect placement), even with the larger sized gloves. It was also felt that the Canadian butyl gloves were tighter across the back of the hand when the thumb and little finger were pinched together when compared to the Australian butyl gloves.

3.6.13 Correspondence Analysis/Glove Index

Subjects' responses to the glove fit and functionality questionnaire were combined (Section 2.4.5) to generate a Glove Index (GI) presented in Figure 4. The negative control glove clearly demonstrated that it was the least preferred glove whereas the Nomex® flying glove and Ansell TNT® were chosen as the most preferred gloves. Interestingly, users rated their preference for the Canadian butyl glove as undecided with the Australian butyl glove being less favourably rated between undecided and least favourable. It is evident from this analysis that the questionnaire could easily distinguish between the different types of gloves. That is, the single layered gloves are grouped together (most preferred), then the double layer gloves in a second distinct group, with the ill fitted negative control being the least favoured option.

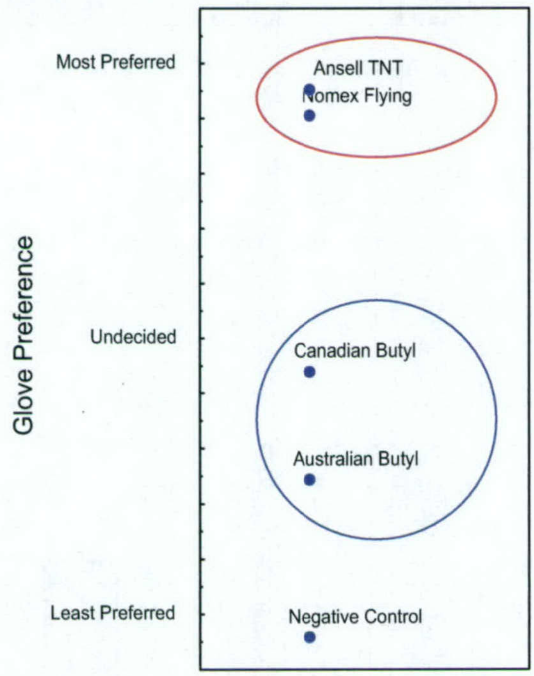
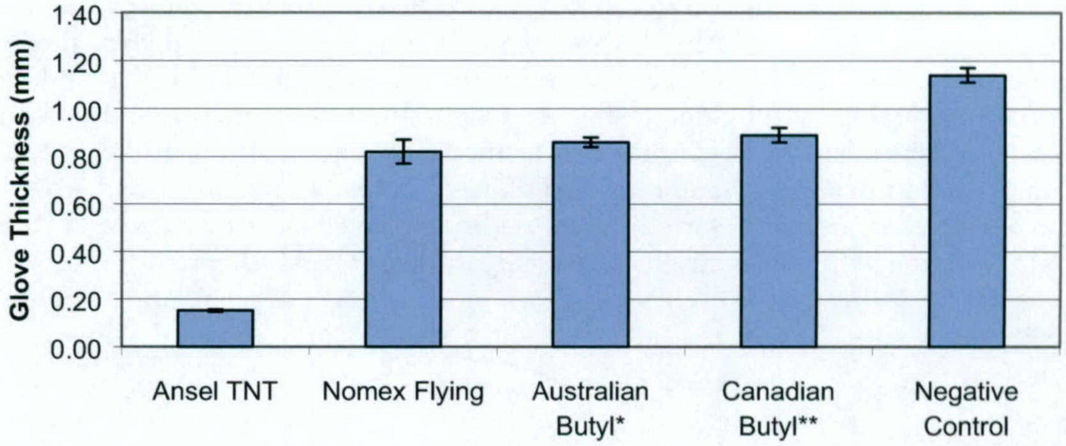


Figure 4 Glove preference as rated by the glove index

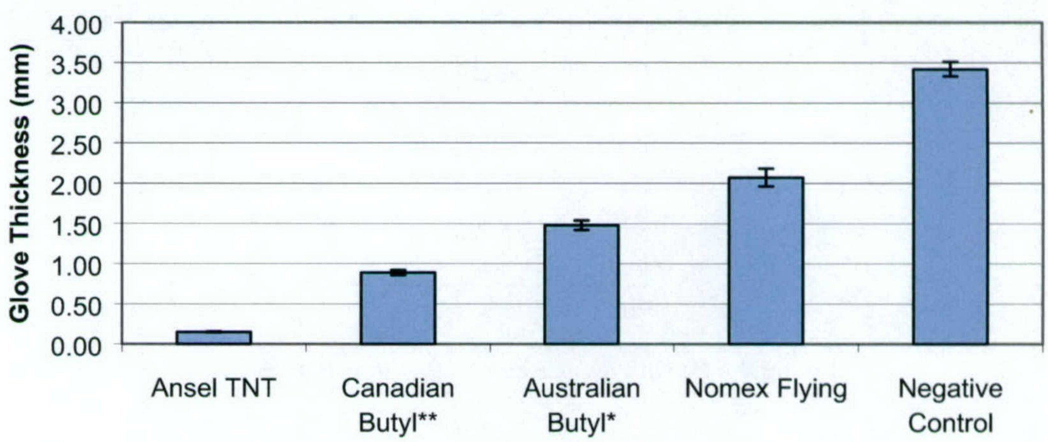
3.7 Glove Thickness

The influence of glove thickness has been found to have a decremental affect on glove tactility and dexterity [2-7]. Consequently, the thickness of each glove (including cotton liners with the Australian and Canadian butyl rubber gloves) was measured at the fingertips (Figures 5 & 6). In Figure 5 the fabric/material thickness of the glove at the fingertip was measured, excluding the influence of any seams that may be present. The Ansell TNT® glove was the thinnest glove. The Nomex® flying, Australian and Canadian butyl gloves then followed and were all similar in thickness. The negative control glove was the thickest glove tested in this study.



* The Australian cotton liner was sewn with seams.
** The Canadian cotton liner was seamless.

Figure 5 Glove thickness at fingertips excluding the influence of seams



* The Australian cotton liner was sewn with seams.
** The Canadian cotton liner was seamless.

Figure 6 Glove thickness at fingertips including the influence of seams

When the impact of seams on the thickness of gloves at the fingertips (Figure 6) was investigated, only the seamless Ansell TNT® glove and Canadian butyl gloves remained unchanged. The Nomex® flying, Australian butyl and negative control glove are all significantly thicker, and a significant difference in the thickness is observed for all gloves. However, a direct comparison between the glove thickness and the performance achieved by subjects during the timed tasks could not be made because the glove materials and structures were all significantly different. The glove thickness trend shown in Figure 6 was similar (with the exception of the Nomex® flying glove) to the trends observed for both the weapon assembly/disassembly and the Purdue pegboard tasks.

As noted in Section 3.4 the Nomex® flying glove has an additional seam on the index finger (which is not present on the other fingers) where the leather is doubled over. This seam was in such a position that it was more of an intermittent problem when caught between the pinch of subjects. This seam was reported to cause problems during the Purdue pegboards task (in particular during the assembly sub task, Figure 2) but not for subjects completing the weapon assembly/disassembly task. The fact that the Nomex® flying glove is a single layer glove, and that seam interference was intermittent is probably reasons why it performed better than all the other gloves with the exception of the Ansell TNT® glove.

4. Discussion

4.1 General

The initial glove priority function questionnaire identified the top 5 glove functions as fit, dexterity, grip, chemical protection and tactility. Glove functions that were not rated highly were typically related to logistics such as cost and shelf life. The gloves used in this study were ranked in the same order for both the weapon assembly/disassembly task and the Purdue pegboard tasks. The Ansell TNT® glove performed the best followed by the Nomex® flying, Canadian butyl, Australian butyl and the negative control glove. Interestingly the Canadian butyl glove tended to have the second best tactility after the Ansell TNT® glove, followed by the Nomex® flying, Australian butyl and negative control. This improved tactility of the Canadian butyl over the Nomex® flying glove failed to provide better performance in the weapon assembly/disassembly task and in the Purdue pegboard task.

The glove fit and functionality questionnaire for individual gloves proved useful in identifying areas of the glove that could be enhanced in future glove design. For example, the Nomex® flying glove was generally well liked by subjects, however the sewn seam on the index finger was identified as an area for improvement. Similarly, it was felt that the in-service Australian butyl rubber gloves could be improved by using knitted rather than sewn cotton liners (as shown by preference for Canadian over

Australian liners. The durability of the Ansell TNT® glove would make it unsuitable for most military operations. The ranking of gloves by the Glove Index (GI) supported the results of both the weapon assembly/disassembly, and Purdue pegboard tasks, as all gloves were ranked in the same order.

The impact of glove thickness on glove performance was difficult to analyse as all the gloves were made of different materials and had different structures. However, it could be seen that the thinnest glove (Ansell TNT®) performed the best and the thicker gloves performed poorer. The remaining gloves (Nomex® flying, Canadian butyl, Australian butyl) were similar in thickness, although seams in the liner of the Australian butyl glove had the potential to adversely affect performance. Similarly the seam on the index finger of the Nomex® flying glove had the potential to adversely affect performance during specific task-dependent objectives such as the Purdue pegboard assembly sub task.

In summary, the major advantages and disadvantages of the glove types are shown in Table 2. Trade offs exist, for example the advantage of excellent chemical protection and durability of the Australian butyl glove comes at the cost of tactility and dexterity.

Table 2 The major advantages and disadvantages of the Ansell TNT®, Nomex® Flying, Canadian butyl and Australian butyl gloves

Glove	Major Advantages	Major Disadvantages
Ansell TNT	tactility, dexterity, single glove	chemical protection, durability
Nomex® Flying	comfort, user acceptability, single glove	not NBC, seams
Canadian butyl	sizing, seamless liner, chemical protection	tactility, dexterity, double glove
Australian butyl	chemical protection, durability	tactility, dexterity, double glove

4.2 Developing a Glove

Based on the outcomes of this study, a preferred NBC glove would be a single glove system similar in construction to the Nomex® flying glove. This has several advantages over a double glove system such as being easier to don and doff. A single glove also has lower logistics burden, as only one glove needs to be procured, stored and carried. The glove should come in a variety of sizes (e.g. as Canadian butyl does) to meet all demographics of the Australian Defence Force.

The ideal glove would provide a combination of chemical, thermal and environmental protection. It would not adversely affect the tactility or dexterity of the wearer performing specific tasks. The glove should be sufficiently durable, affordable, readily available and have a long shelf life. The glove should be inherently safe (non toxic to skin and non-allergenic).

Although sweat accumulation was not a focus of this study it was however, one of the major drawbacks and complaints associated with the air impermeable gloves (e.g. Ansell TNT®, Australian and Canadian butyl). The Australian and Canadian butyl rubber gloves attempt to alleviate the accumulation of sweat by providing a cotton liner. Unfortunately the cotton liners have a finite capacity for sweat accumulation and can become saturated. A major advantage of air-permeable gloves (e.g. Nomex® flying, negative control) is that they allow for the evaporation of sweat, and create less of a barrier to the body's natural ability to cool. However, this added comfort comes at a cost as air impermeable butyl rubber gloves offer superior protection against chemical warfare agents. Fabric gloves also have the potential to offer improved dexterity, as the fabric is more likely to stretch and conform naturally to the hand's shape compared to the impermeable butyl rubber gloves. Thinner impermeable rubber gloves (such as the Ansell TNT®) can conform well to the shape of the user's hand but typically are not durable enough for military operations.

Currently no NBC glove is available that satisfies all of the military operational requirements. In some circumstances the Australian butyl rubber glove limits soldier's performance (Table 3).

Table 3 The major advantages/disadvantages of the Australian butyl rubber glove

Major Advantages	**Major Disadvantages**
	Double glove
Good chemical protection	Cotton liner has seams
Butyl rubber is seamless	Sizing
Durable	Sweat accumulation
Cheap	Poor tactility compared to bare hands
Long shelf life	Poor dexterity compared to bare hands
	Difficult to don/doff
	Poor comfort

However, a hybrid glove with various traits from the gloves tested containing a combination of butyl ruber and flame retardant chemical protective fabric could potentially improve a soldier's acceptance and enhance performance over the current glove. The fingers and palm of the hand could be covered with butyl rubber whereas the back of the hand and cuff could be made of protective fabric. A double fabric cuff system could then be developed to enhance integration with the existing MK IV NBC protective overgarment.

5. Conclusions

The Australian butyl rubber glove tended to have a similar performance to the Canadian butyl rubber glove in terms of dexterity, as measured by both the weapon assembly/disassembly task and Purdue pegboard tasks. However, the dexterity of the Australian butyl rubber glove was not as good as the Nomex® flying glove. The tactility of the Australian butyl rubber glove tended to be poorer than all the other gloves (Ansell TNT®, Nomex® flying, Canadian butyl). The most favourable traits of the Australian butyl rubber glove are its NBC protection and durability. However, this comes at the cost of tactility and dexterity. Typically subjects felt that if the Nomex® flying glove offered NBC protection and had the seam removed on the index finger it would make an ideal NBC glove. Based on the outcomes of this study a preferred NBC glove is a single layered glove that offers good levels of chemical protection whilst maintaining adequate levels of tactility and dexterity. The glove should be comfortable, durable, and come in a large range of sizes.

This document forms a basis in which the perfomance of new NBC gloves can be scientifically compared in terms of tactility and dexterity to the current Australain NBC butyl rubber glove. The outcomes of this study will form the basis from which a requirements document for a new NBC glove will be generated.

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Appendix A: Information For Prospective Volunteers

A Comparative Dexterity and Tactility Study of Selected Gloves used by the Australian Military

A.1. What the study is about

In a NBC contaminated environment there are several situations in which gloves can become the limiting factor, in terms of task performance output. In general, performing operational tasks while wearing gloves can prolong work times leading to frustration, and many tasks may be hindered or unsuccessful while gloved but posed very little burden when un-gloved. This study aims to provide a benchmark in terms of tactility and dexterity for the Australian in-service NBC butyl rubber glove and Nomex® flying glove for standardised and operational tasks. A comparison of dexterity and tactility will also be made to three other commercially available chemical protective gloves (Canadian NBC Butyl Rubber Glove, Ansell TNT® Nitrile Glove and negative control Air Permeable NBC Glove). The information from this study will provide both qualitative and quantitative rankings of the gloves assessed and will be available for the future design of gloves used by the ADF.

A.2. Your Part in the Glove Study (should you choose to participate)

1. Twenty four participants (12 DSTO staff and 12 ADF personnel) are required to perform standardised dexterity and tactility tests (DSTO staff) and weapon assembly and disassembly tasks (ADF personnel) whilst wearing a range of gloves. The task requires minimal physical and mental exertion from a static position. The other tasks will involve the completion of questionnaires.

2. Your decision to participate in this study is entirely voluntary. This means that:

- There is no obligation on you to participate.
- There is no obligation on you to continue participating.
- If you refrain or withdraw from participation, there will be no detriment to your career or hindrance to access to appropriate medical care.

3. You may experience some discomfort in your hands due to repeated manual manipulations.

4. If you feel you cannot continue with any part of the experiment, you may stop immediately. You are encouraged to voice any concerns, no matter how trivial or awkward they may seem.

A.3. Restrictions on Participation

5. Those who have been diagnosed as having RSI (repetitive strain injury) in the past or present are asked not to participate.

A.4. Risks of Participating

6. **Masceration:** This occurs when gloves are worn for extended periods of time and sweat build-up is not adequately removed away from the skin. It can result in wrinkling and discomfort of the skin similar to what occurs from extended bathing.

7. **Cramps:** Cramping of the hands/fingers may occur from preforming the repeated dexterity tasks, the risks of these occurring are low if adequate breaks are taken.

A.5. Duty Status

8. You are considered to be on duty during your participation in this study.

A.6. Privacy of Information

9. All information relating to your participation in this study is confidential. You are under no obligation to provide any information that, for whatever reason, you do not wish to divulge.

10. All knowledge of your responses will be kept under lock and key, accessible only to the project team, in accordance with the Guidelines of the National Health and Medial Research Council.

11. Knowledge of your responses will be made available only to you, unless your identity is first coded to prevent recognition.

12. Any personal data collected will be used for the purpose of this project and no other, without express permission of yourself.

A.7. The Project Team

13. The Project team is:

a. Mr. Steven Scanlan, Defence Science and Technology Organisation

b. Mr. Warren Roberts, Defence Science and Technology Organisation

14. You are encouraged to read the accompanying copy of the Australian Defence Medical Ethics Committee Guidelines for Volunteers. Should you have any concern, query or complaint concerning the manner in which the research project is conducted,

please do not hesitate to contact Mr. Graeme Egglestone, either in person, or at the following addresses:

Mr. Graeme Egglestone
Defence Science & Technology Organisation
PO Box 4331, GPO Melbourne, VIC 3001
tel: (03) 9626 8428
fax: (03) 9626 8410
e-mail: graeme.egglestone@dsto.defence.gov.au

Alternatively, you may prefer to contact the Australian Defence Human Research Ethics Committee at the following address:

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Australian Defence Human Research Ethics Committee
CP2-7-66
Department of Defence
CANBERRA, ACT 2600
tel: (02) 6266 3925
fax: (02) 6266 4982
e-mail: hlthpol@bigfoot.com

Appendix B: Consent Form

A Comparative Dexterity and Tactility Study of Selected Gloves used by the Australian Military

I, ... *Name)* .... *(Rank)* give my consent to participate in this Comparative Dexterity and Tactility Study of Selected Gloves used by the Australian Military.

I have had explained to me the aims of this study, how it will be conducted and my role in it. I have had my questions answered satisfactorily and I am happy to participate. I understand that:

- I am under no obligation to volunteer for this project and that I can withdraw at any time without detriment to my career or without compromise to my medical care.
- I am considered to be on duty during my participation in the study.
- Monitoring will include measurement of the time taken to complete dexterity tasks, response to touch (tactility test), and questionnaires on 'priority ranking of glove functions" and "glove fit and functionality".

To the best of my knowledge, none of the conditions listed in the Restrictions on Participation section of the Information Sheets apply to me.

I agree to abide by all instructions concerning the conduct of all tests in this project.

I am cooperating in this project on condition that:

- The information I provide will be kept confidential.
- The information will be used only for this project.
- The research results will be made available to me at my request.

Any reporting of this study will preserve my anonymity.

I have been given a copy of the information sheet, a copy of ADHREC's Guidelines for Volunteers, and this form, signed by me and by the Project Manager, Mr Steven Scanlan.

Signed...*Date* / /

Witness...*Date* / /

Signature of Officer in charge of this project .

....

Appendix C: Questionnaire 1

C.1. Priority Ranking of Glove Functions (Modified from Torrens G.E., McAllister C., Westwood E., & Williams G.L.)

(To be completed prior to the trial)

Subject..

Age..

Gender..

Are you left or right handed?..

What glove(s) do you normally wear? ....
....
....
....

Glove Functions	Score (circle one answer) Least Important Most Important
Fit	0 1 2 3 4 5 6 7 8 9
Dexterity (manipulative ability)	0 1 2 3 4 5 6 7 8 9
Tactility (sense of touch)	0 1 2 3 4 5 6 7 8 9
Grip	0 1 2 3 4 5 6 7 8 9
Durability	0 1 2 3 4 5 6 7 8 9
Chemical Protection	0 1 2 3 4 5 6 7 8 9
Thermal Insulation	0 1 2 3 4 5 6 7 8 9
Comfort	0 1 2 3 4 5 6 7 8 9
Sweat Removal	0 1 2 3 4 5 6 7 8 9
Ease of donning/doffing	0 1 2 3 4 5 6 7 8 9
Integration with existing equipment	0 1 2 3 4 5 6 7 8 9
Shelf life	0 1 2 3 4 5 6 7 8 9
Cost	0 1 2 3 4 5 6 7 8 9
Easy to remove from packaging	0 1 2 3 4 5 6 7 8 9
Weight	0 1 2 3 4 5 6 7 8 9
Bulk	0 1 2 3 4 5 6 7 8 9
Free from odour	0 1 2 3 4 5 6 7 8 9

Appendix D: Questionnaire 2

D.1. Glove Fit and Functionality (Modified from Torrens G.E., McAllister C., Westwood E., & Williams G.L.)

(To be completed for each glove at the end of the dexterity/tactility testing)

In the following table please indicate your response by marking only one box to each question

Statement	Strongly Agree	Agree	No Preference	Disagree	Strongly Disagree
The gloves fit me well at the fingertips and thumb?					
The gloves fit me well at the knuckles?					
The gloves fit me well at the wrist?					
I can load my weapon easily with gloves on?					
I can disassemble and reassemble my weapon easily with gloves on?					
I can easily handle ammunition with my gloves on					
I can easily do jobs such as typing and writing with my gloves on?					
Training will improved my ability to perform tasks wearing gloves?					
The gloves are sufficiently durable?					
The gloves are not tactile enough (sense of touch)?					
The gloves are not dextrous enough (manipulative ability)?					
Wearing the gloves I can adequately perform my mission?					
The gloves are easy to don					
The gloves are easy to doff					
The gloves are to tight					
The gloves are sticky					
The gloves interfere with the equipment that I use					
I anticipate problems with the gloves operationally					

For the last two questions please indicate what equipment or operations you see the gloves being a problem with?..

....

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S. Scanlan, W. Roberts, R. McCallum and D. Robinson

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19. ABSTRACT

This report details the tactility and dexterity of four different glove types, including the Australian in-service NBC butyl rubber glove and Nomex® flying glove for standardised (Purdue pegboard) and operational (weapon asembly/disassembly) tasks. The Nomex® flying glove was included for comparative purposes despite offering no NBC protection . Two commercially available chemically protective gloves (the Canadian NBC butyl rubber glove, Ansell TNT® nitrile glove) were also assessed. Twenty-four healthy male subjects participated in the study. Subjects completed two questionnaires, one on the priority of glove functions and the second on glove specific fit and fuctionality. Subjects completed either the weapon assembly/disassembly task or the Purdue pegboard task. The results from both these tasks were consistent for all gloves and in agreement with the reponses recorded on the questionnaires. The Ansell TNT glove tended to provide the best dexterity scores followed by the Nomex flying, Canadian butyl and Australian butyl gloves. The Ansell TNT glove tended to be the most tactile glove followed by the Candian Butyl, Nomex flying and Australian butyl. Subjects felt their performance in the Australian Butly rubber glove could be enhanced through training and by adopting seamless liners similar to those used in the Canadian system. Overall subjects preferred single layered, seamless gloves that had a low impact on task-dependant dexterity and tactility. Typically subjects felt that if the Nomex flying glove offered NBC protection and had the seam removed on the index finger it would make an ideal NBC glove. The outcomes of this study provide a scientific basis from which a requirements document for a new NBC glove could be generated. It is intended that the most favourable features of a glove identified during this study will be used in future ADF NBC glove designs.