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Advancing Military Readiness through Multidisciplinary Innovations

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ABOUT FRONTIER

FRONTIER is a Defence Science and Technology (DS&T) journal formatted under the guidance of the Defence Science and Technology Group (DSTG), for the periodic publication of a curated set of articles, reports and technical papers written by members of the Ministry of Defence (MINDEF) and the Royal Brunei Armed Forces (RBAF), as well as the institutions of higher learning in Brunei Darussalam.

Through publication and hence sharing of DS&T content, FRONTIER aspires to be a platform that creates awareness, generates discussion an inculcates innovation among members of the DS&T community.

In alignment with the ongoing digitisation effort spearheaded by DSTG, FRONTIER will be made available primarily as softcopy via the MINDEF official website. Limited hard copies of FRONTIER will also be distributed to MINDEF and RBAF leaderships and made available in MINDEF and RBAF libraries.

FOREWORD

Hasrinah binti Matyassin
Editor-in-Chief

The Defence Science and Technology Group (DSTG) is pleased to release FRONTIER's Fifth Volume featuring the theme '***Advancing Military Readiness Through Multidisciplinary Innovations***'.

This edition of FRONTIER features five articles, which present a variety of studies conducted by Ministry of Defence (MINDEF) and higher academic institutions of Brunei Darussalam specifically Universiti Brunei Darussalam, Universiti Teknologi Brunei and Laksamana College of Business in an effort to explore diverse topics crucial for military preparedness, from biomechanics to communications optimization. Addressing issues like nutritional provisions, they underscore the importance of innovation in maintaining military readiness. Additionally, the volume highlights the practicality of 3D scanning technologies for equipment maintenance.

'Biomechanical Characteristics of the Lower Limb in Military Cadets: Its Risk Factor for Injury and Relationship with Lower Extremity Flexibility' analyses lower limb biomechanics in military cadets, finding high rates of flat-footedness, knee deformities, and overpronation. Foot pronation significantly influenced iliotibial band (ITB) tightness, impacting injury rates. Tailored interventions addressing ITB-related factors and foot pronation could reduce overuse injuries in cadet training programs.

'Optimising Communications Information Systems Support on Operations: How Can 5G Network Boost Military Capabilites?' discusses the military's growing dependence on wireless technology to improve situational awareness and operational efficiency. It explores the benefits and challenges of integrating cutting-edge wireless technologies, such as 5G, including spectrum management and infrastructure sharing with commercial networks, to meet modern warfare needs.

'***Prevalence of Self-Reported Work-Related Injuries and Their Associated Risk Factors Among the Royal Brunei Armed Forces (RBAF) and Ministry of Defence (MINDEF) Military Personnel***' surveys RBAF and MINDEF military personnel, finding a high rate of work-related injuries, especially in the lower body and lower back. Factors like non-commissioned officer status, poor sleep, and unhealthy habits are linked to injuries, highlighting the need for targeted interventions in physical training practices and injury prevention strategies for military personnel.

‘***Evaluation of Nutritional Values in Herbal Cookies Infused with Murraya koenigii and Gnetum gnemon***’ analyses five different ratios of plant powder combinations for their nutritional values. Cookies with 100% Murraya koenigii had the highest energy and protein, while those with 25% Murraya koenigii and 75% Gnetum gnemon had the highest carbohydrate content. These adaptable formulations could meet diverse dietary needs, offering potential as portable, energy-dense provisions, especially in demanding environments like military settings.

‘***Defense Logistics: An in-depth analysis of 3D Scanning Technologies and how to use them to replace damaged parts***’ highlights the practicality of low-cost 3D scanners, specifically the CR-Scan Lizard, in replicating damaged objects. It outlines the scanner's technology, usage methods, tips for better scans, and limitations. Overall, it aims to promote the wider use of 3D scanners as an accessible solution for repairing damaged items.

In summary, the studies in FRONTIER's Volume 5 highlight the importance of innovation in strengthening military readiness. Covering diverse areas like biomechanics, communication technology, nutrition and injury prevention, each study provides valuable insights for enhancing military capabilities. Moreover, the findings from these studies exemplify the military's commitment to staying adaptable and resourceful in the face of evolving challenges. Additionally, the exploration of 3D scanning technologies offers practical solutions for equipment maintenance, further emphasizing the importance of innovation in ensuring readiness for future operations.

ABOUT THE AUTHOR

Ahmad Dzulkhairi bin Awang Haji Mail is an assistant researcher from Human Performance Lab, Performance Optimisation Centre (POC). He earned his Sports and Exercise Science degree from Swansea University, Wales. His primary focus of expertise centers around sports biomechanics and exercise physiology. His current research endeavours are directed towards the biomechanical characterization of feet within the Royal Brunei Armed Forces (RBAF). His work aims to optimise the selection of appropriate running shoes and assist the RBAF in issuing proper combat footwear, such as jungle boots and boots for seamen, pilots, and paratroopers. The author's dedication to exploring footwear ergonomics promises to benefit the organisation's personnel across various operational contexts.

Biomechanical Characteristics of the Lower Limb in Military Cadets: Its Risk Factor for Injury and Relationship with Lower Extremity Flexibility

Author:
Ahmad Dzulkhairi bin Awang Haji Mail, POC

A B S T R A C T

The primary purpose of this study was to analyze the biomechanical characteristics of the lower limb, including foot types, foot pronation, knee alignment, and hip function, and identify potential risk factors for musculoskeletal injuries during basic military training. The secondary purpose was to examine their relationship to lower extremity flexibility, such as iliotibial band flexibility and ankle mobility. Data from 258 officer cadets (age: 25.0 ± 2.2 years, gender: 185 males, 73 females, height: 1.63 ± 0.07 m, weight: 63.6 ± 8.8 kg) was used for this study. All data were analyzed retrospectively, and all biomechanical characteristics were done by qualitative visual appraisals. Injury occurrence data were collected at two time points, mid-training and post-training. The majority of the cadets were found to be flat-footed (49%, N=188), 63% (N=132) had some form of knee deformity (valgus/varus), 84% (N=258) were overpronators, and 92% (N=258) had gluteal weakness or hip dysfunction. On the other hand, 70% (N=258) had good ankle mobility, and 53% (N=258) had at least one side deemed positive for iliotibial band (ITB) tightness. Furthermore, it was found that foot pronation had a significant influence ($P<0.05$) on ITB tightness. ITB flexibility had a significant effect ($p<0.05$) on the injury incidence sustained during their cadet training. This finding highlights the importance of addressing ITB-related factors to reduce the risk of overuse injuries and the influence of foot pronation on ITB flexibility, emphasizing the need to consider the biomechanical interactions within the lower extremities, suggesting that military cadet training programs can benefit from tailored interventions aimed at improving ITB flexibility and addressing foot pronation issues.

Keywords:

Biomechanical characteristics, lower limb, musculoskeletal injuries, military training, foot types, foot pronation, ankle mobility, knee alignment, hip function, tailored interventions.

1.0 INTRODUCTION

The relationship between foot type and musculoskeletal (MSK) flexibility is crucial in military training and performance. Foot types, characterized by arch structure and alignment variations, have been implicated in numerous MSK conditions and injuries among active-duty military personnel [1]. These conditions, such as stress fractures, plantar fasciitis, and Achilles tendonitis, can significantly impact an individual's operational readiness and overall physical well-being during military service. Understanding the prevalence and implications of various foot types in military populations is crucial for injury prevention and long-term performance optimisation.

Foot pronation, the inward or outward rolling of the foot during walking or running, is closely linked to knee alignment and can influence pronation and flexibility [2,3]. Improper pronation and knee alignment can lead to compromised movement patterns, increased knee stress, and heightened vulnerability to injuries, particularly in physically demanding military tasks. On the other hand, hip abductor dysfunction, characterised by a pelvis dropping on the unsupported side during walking, can result from various factors, including hip abductor weakness and lower extremity inflexibility [4]. This gait abnormality can contribute to hip and lower back pain, affecting military personnel's overall mobility and functional capacity. Thus, lower extremity flexibility is integral to preventing and addressing abnormalities, enabling a broader range of motion and proper biomechanical alignment. Furthermore, lower extremity flexibility is pivotal in preventing injuries and optimising physical performance.

Limited flexibility can lead to compromised movement patterns and increased vulnerability to injuries, particularly in physically demanding military tasks like running, marching, and combat training. Thus, understanding how specific foot types may influence lower extremity flexibility in this demographic is crucial for devising effective training programs and injury prevention strategies. This paper aims to bridge this gap by presenting a detailed analysis of the biomechanical characteristics of the lower limb, which includes foot types, foot pronation, knee alignment, and hip function, and determining these characteristics as potential risk factors for MSK injury amongst officer cadets. Secondly, is to examine the relationship of these characteristics to lower extremity flexibility and whether effects on flexibility can be seen as potential risk factors for MSK injury amongst officer cadets. Findings in this paper hold the potential to inform us about targeted interventions that can be used to help reduce MSK injuries seen in basic military training.

2.0 METHODOLOGY

2.1 Participants

A total of 258 officer cadets (age: 25.0 ± 2.2 years, gender: 185 males, 73 females, height: 1.63 ± 0.07 m, weight: 63.6 ± 8.8 kg) from OCS intake 18 until 21 took part in the Fitness Assessment and Screening, and Musculoskeletal Injury Surveillance (FIT RISE) project, which consisted of three data collection periods throughout their 48-week cadet training.

2.2 Study design

All data were analysed retrospectively to establish a baseline understanding of the biomechanical characteristics of the lower limbs. However, the results for foot types and knee alignments used in this study were limited to only 188 and 132 officer cadets, respectively. This is because the data for foot types were not collected in intake 20, and the collection of the knee alignment data was discontinued from intake 20 onwards. All biomechanical characterization data were derived only from the pre-enlistment fitness assessment screening data collection (pre-FAS). On the other hand, injury incidence (INJ) data comprised present and past injuries reported during mid-training FAS (mid-FAS) and past injuries during post-training FAS (post-FAS). This is illustrated in **Figure 1** below.

2.3 Procedures

Questionnaire

All participants were provided with a written informed consent form and were required to complete a questionnaire that included questions about any past and present injuries, particularly sustained during cadet training. Past injuries are any MSK injuries sustained between the previous and current data collection points. For example, past injuries collected during Mid-FAS are MSK injuries sustained between Pre-FAS and Mid-FAS in which the cadets have already recovered before Mid-FAS data collection. Whereas present injuries are any MSK injuries sustained during the time of data collection. The questionnaire collected information on the injury location, type, time, treatments, whether it prevented them from engaging in any physical activity, and whether they have since recovered.

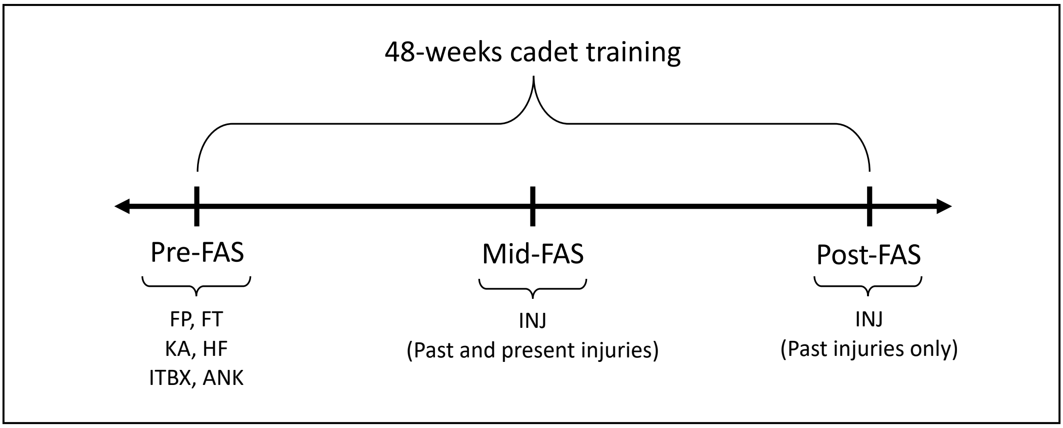

Figure 1. Diagram of data collection procedure. *Key:* ***FP****=foot pronation,* ***FT****=foot type,* ***KA****=knee alignment,* ***HF****=hip function,* ***ITBX****=ITB flexibility,* ***ANK****=ankle mobility,* ***INJ****=injury incidence.*

Foot pronation

All biomechanical characterisations of the participants were done by qualitative visual appraisals. To assess foot pronation, participants were asked to walk on a treadmill (HP Cosmos, LE 200 CE) at a speed of 4 km/h. If the foot rolled inwards or outwards, it was deemed over-pronating or over-supinating, respectively, as shown in **Figure 2** [5].

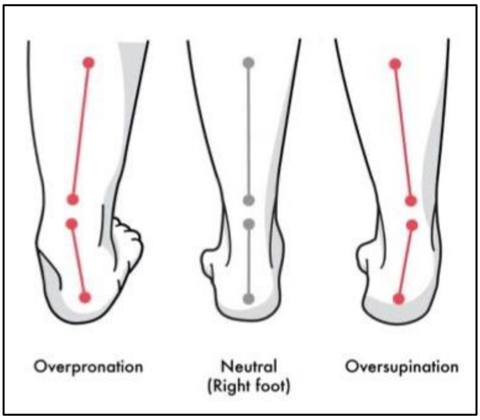

Figure 2. Diagram of foot pronation.

Foot type

To determine foot types, participants were instructed to stand with their feet shoulder-width apart while the examiner visually assessed their feet and used their fingers when needed. If the examiner could fit their entire finger below the feet, the participant was considered to have high arches, while if the finger could not fit below the feet at all, they were deemed to have flat feet. If only part of the finger could be fitted below the feet, the participant was considered to have normal arches. **Figure 3** below illustrates 3 different foot types [6].

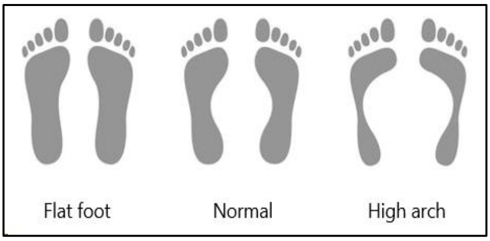

Figure 3. Diagram of foot types.

Knee Alignment

The examiner will assess the knee from the frontal view to determine knee alignment. If the knee passes medially to the knee center, a valgus deformity is present; if the line passes laterally to the knee center or center of the distal femur, a varus deformity exists. This is illustrated in **Figure 4** below [7].

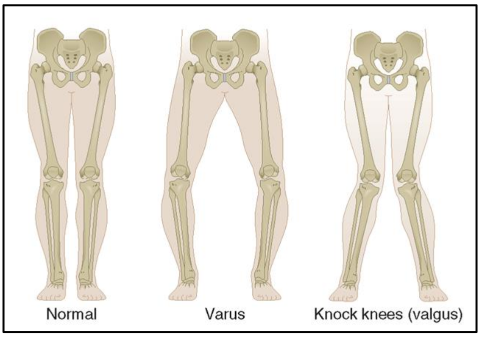

Figure 4. Diagram of knee alignment.

Hip Function

On the other hand, hip function is determined using Trendelenburg's test [8]. Participants were asked to walk on a treadmill at a speed of 4km/h while the examiner assessed whether a pelvic tilt was present during the stance phase of the gait. If present, the participant will be deemed positive, otherwise negative for gluteal weaknesses. **Figure 5** illustrates the difference between normal and abnormal hip function [9].

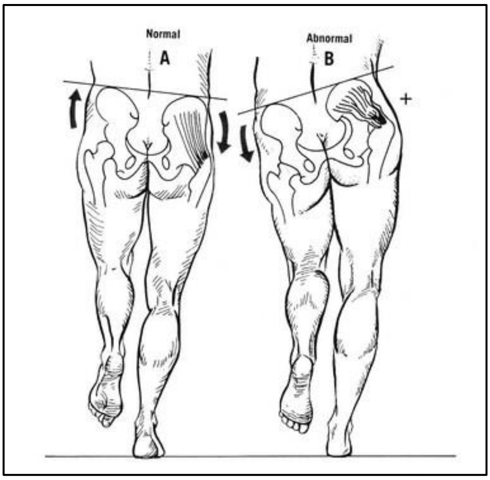

Figure 5. Diagram of a normal and abnormal hip function.

ITB Flexibility

ITB flexibility was evaluated using Ober's test [10]. Participants were asked to lie sideways on a massage bed with the bottom knee and hip flexed. This is shown in **Figure 6** below [11].

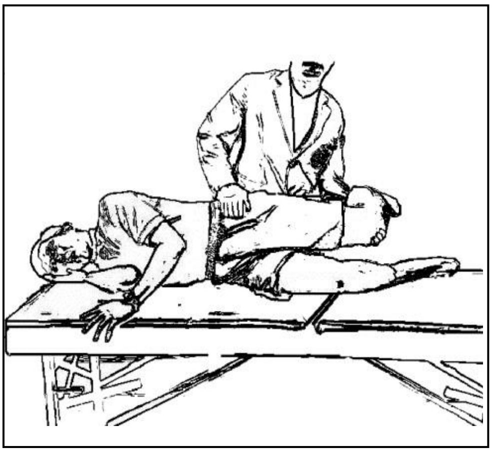

Figure 6. Diagram of the Ober's test.

The examiner then grasped the distal end of the leg on top while flexing the leg to a right angle at the knee. The top leg will be extended and abducted by the hip joint before slowly being lowered towards the bed. Participants will be deemed negative for ITB tightness if the top leg drops below the horizontal, while they will be marked positive if the leg remains abducted.

Ankle Mobility

Lastly, the Ankle Clearing test was utilized to determine ankle mobility, as shown in **Figure 7** [12]. The Functional Movement Screening (FMS) test kit was used for this test. Participants' feet were positioned in a heel-to-toe position, with the medial part of the back foot aligned to and touching the side of the test kit behind the zero line. They were then instructed to drop straight down, bending the knee and taking the back knee as far as possible in front of the toes with the heels down. The distance of the knee of the back foot to the medial malleolus will then be measured to determine whether the participant reached behind or beyond the zero line. Participant will be marked 'behind' if their knees did not pass the zero line, and 'beyond' if they passed the zero line. Participants will then be categorised into 'both behind', 'one side beyond', and ''both beyond' if both side of their knees reached behind, either one side reached beyond, and both sides reached beyond, respectively.

Figure 7. Ankle Clearing test.

2.4 Statistical analyses

All data were entered and organized using Microsoft Excel 2021. Data normality was evaluated using the Shapiro-Wilk test. The Kruskal-Wallis test was performed on parameters that were found to have violated the homogeneity of variance. To assess the significance of the independent variables (lower limb flexibility and injury incidence) based on the dependent variables (lower limb characteristics), a one-way analysis of variance (one-way ANOVA) was used. All statistical analyses were performed using the Statistical Package for Social Sciences version 26 (SPSS 26, IBM Corp). Figures and data are illustrated as mean ± standard deviation (SD), where applicable, with significance defined as $p \leq 0.05$.

3.0 RESULTS

Data from 258 officer cadets were reviewed for this study. The descriptive statistics of the participants' physical characteristics are shown in **Table 1**. Meanwhile, details on participants' biomechanical characteristics of their lower limbs and lower limb flexibility are shown in **Tables 2** and **3**, respectively.

Table 1. Physical characteristics of participants.

Parameters					95% CI Interval	
		N	Mean	SD	Lower	Upper
Age (years)	Male	185	24.8	2.5	24.5	25.2
	Female	73	25.6	1.5	25.1	25.8
	Total	258	25.0	2.2	24.7	25.3
Height (m)	Male	185	1.68	0.05	1.67	1.68
	Female	73	1.57	0.04	1.57	1.58
	Total	258	1.65	0.07	1.64	1.66
Weight (kg)	Male	185	66.7	7.9	65.6	67.8
	Female	73	55.9	5.9	54.6	57.3
	Total	258	63.6	8.8	62.6	64.7

Table 2. Biomechanical characteristics of participants' lower limb.

Parameters		N	%
FT (*N*=188)	Flat	93	49.5
	One side flat	27	14.4
	Normal	65	34.6
	One side high arch	3	2.2
	High arch	0	0.0
	Flat + high arch	0	0.0
KA (*N*=132)	Normal	49	37.4
	Varus	55	42.0
	Valgus	27	20.6

FP **(*N*=258)**	Normal	33	12.8
	Overpronation	216	83.7
	Oversupination	9	3.5
HF **(*N*=258)**	Negative	19	7.4
	Positive	239	92.6

Table 3. Participants' lower limb flexibility.

Parameters		N	%
ITBX **(*N*=258)**	Negative	120	46.5
	One side positive	63	24.4
	Both sides positive	75	29.1
ANK **(*N*=258)**	Both sides behind	22	8.5
	One side behind	56	21.7
	Both beyond	180	69.8

Biomechanical Characteristics of the Lower Limb

The participants' lower limb biomechanical characteristics are illustrated in **Figures 8a – 8d**. A total of 93 (49%) officer cadets were flat-footed, 27 (14%) had a mixture of flat and normal, 65 (35%) had normal, and only 3 (2%) had a combination of normal and high arch. Meanwhile, no cadets were recorded to have both feet high arched or a combination of flat and high arches.

Out of 132 participants, 54 (42%) had varus deformity, 49 (37%) were normal, and 27 (21%) had valgus deformity. For foot pronation, a total of 216 (84%) officer cadets were overpronators, 27 (13%) had normal pronation, and only 9 (3%) were oversupinators. Lastly, 239 (93%) officer cadets were reported to have a positive Trendelenburg's test, while only 19 (7%) were deemed negative.

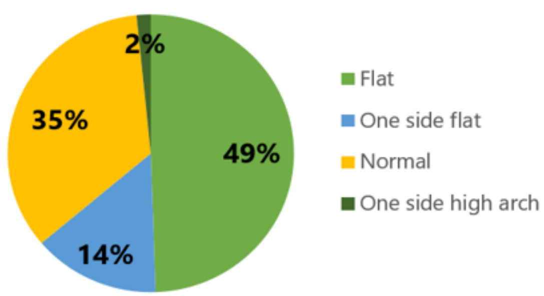

Figure 8a. Foot types.

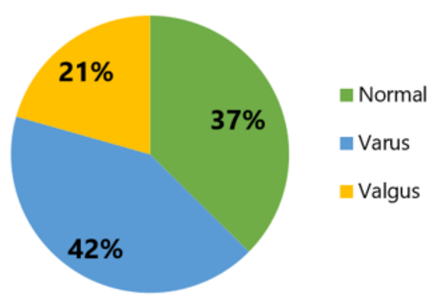

Figure 8b. Knee alignment.

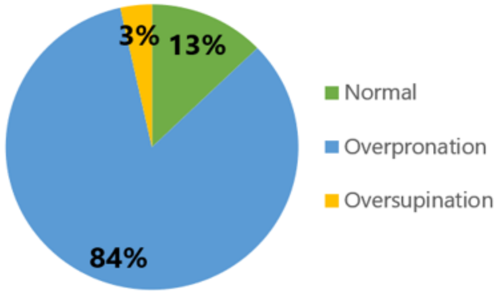

Figure 8c. Foot pronation.

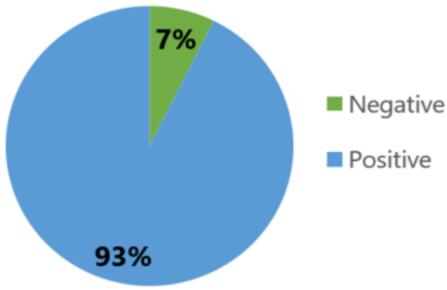

Figure 8d. Hip function.

Lower Extremity Flexibility

Following the ankle clearing test, 180 (70%) cadets scored beyond for both feet, 56 (22%) scored behind on one side of their foot, and 22 (8%) reached behind the zero line for both feet. Meanwhile, a total of 120 (47%) were negative for ITB tightness, 63 (24%) had one side deemed positive, and 75 (29%) had both sides positive for tightness. These results are illustrated in **Figures 9a** and **9b**.

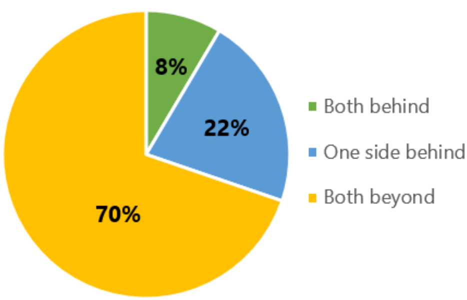

Figure 9a. Ankle clearing reach.

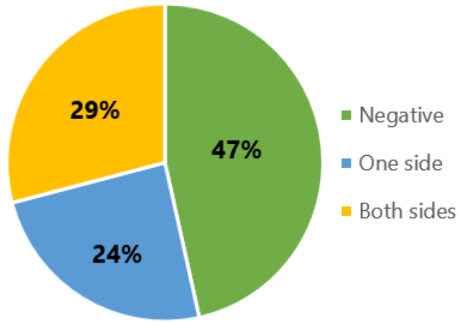

Figure 9b. Ober's test results.

Injury Incidence

As shown in **Figure 10**, a total of 116 (45%) participants reported sustaining injury at least once during their cadet training. Meanwhile, the remaining 142 (55%) reported never getting injured.

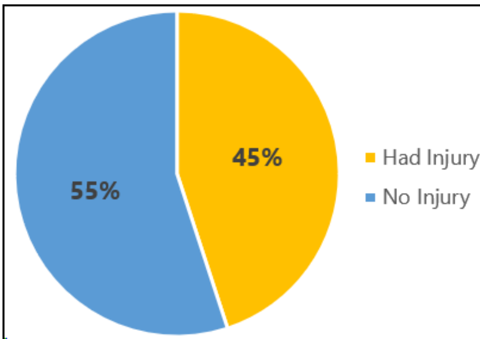

Figure 10. Participant's injury incidence.

Lower Limb Characteristics vs. Flexibility and Injury Incidence

Table 4 shows the statistical findings of the effects of the main factors (lower limb characteristics) on lower limb flexibility and injury incidence. One-way ANOVA revealed only one main factor (foot pronation) had a significant effect on participants' ITB flexibility (*F*=3.423, *P*<0.05).

Table 4. Participants' lower limb characteristics vs. flexibility and injury incidence.

Parameters		*N*	*F-statistic*	*P*-value
FT	ITBX	188	1.002	0.386+
KA		132	0.125	0.882
FP		258	3.423	0.034*
HF		258	0.431	0.650
FT	ANK	188	1.465	0.234
KA		132	1.023	0.356+
FP		258	0.274	0.718+
HF		258	0.932	0.394+
FT	INJ	188	0.021	0.993+
KA		132	2.672	0.105
FP		258	0.493	0.483
HF		258	2.752	0.098+

Key: ***ITBX***=*ITB flexibility*, ***ANK***=*Ankle mobility*, ***INJ***=*Injury incidence*, ***FT***=*Foot types*, ***KA***=*Knee alignment*, ***FP***=*Foot pronation*, ***HF***=*Hip function.*
**P<0.05*
+Asymptotic significance (Kruskal-Wallis)

Lower Limb Flexibility vs. Injury Incidence

As illustrated in **Table 5**, there was a significant effect of ITBX on INJ (*F*=6.545, *P*<0.05). Meanwhile, the effects of ANK revealed otherwise.

Table 5. Participants' lower limb flexibility vs. injury incidence.

Parameters		*N*	*F-* statistic	*P*-value
ITBX	INJ	258	6.545	0.002+*
ANK		258	0.555	0.573+

Key: ***ITBX***=*ITB flexibility*, ***ANK***=*Ankle mobility*, ***INJ***=*Injury incidence.*
**P<0.05*
+Asymptotic significance (Kruskal-Wallis)

4.0 DISCUSSIONS

Understanding foot types in military populations may potentially help prevent injuries and improve performance. The purpose of this study was to present a detailed analysis of the biomechanical characteristics of the lower limb and its risk factors for potential injuries among officer cadets from the OCS during their 48-week cadet training and to examine their relationship to lower extremity flexibility, such as ITB flexibility and ankle mobility.

Lower Limb Characteristics

Approximately 49% of officer cadets have been found to have flat feet. This finding is consistent with previous research that has also shown higher rates of flat feet among military populations [13,14]. Interestingly, approximately 14% of the officer cadets exhibited a combination of flat and normal arches, indicating that some individuals may have varying arch heights. Menz et al. [15] have conducted research indicating that arch height may vary naturally among individuals, and it may not always be directly linked to injury risk. Nevertheless, it is essential to note that individuals with flat feet, particularly those who experience overpronation (excessive inward rolling of the foot), may be at an increased risk for certain lower limb injuries, such as plantar fasciitis and shin splints [16,17]. Consequently, those with mixed arches should remain vigilant for any indications of overpronation or related discomfort, which may necessitate specific interventions, such as orthotic inserts or targeted exercises, to address biomechanical concerns. On the other hand, high arches were relatively uncommon in this study, with only 2% of cadets displaying this trait. It should be noted that the definition of high arches may differ between studies, so it is essential to consider this when interpreting results.

The prevalence of knee alignment deformities among cadets is noteworthy, with 42% demonstrating varus deformity and 21% displaying valgus deformity. These results suggest that a significant portion of the officer cadets may be at risk for knee-related issues such as anterior cruciate ligament (ACL) injuries, patellofemoral pain syndrome, and ITB syndrome [18,19,20]. These conclusions align with the observations made by Nakagawa et al. [21], whose research found similar patterns among military recruits.

Furthermore, a majority (84%) of officer cadets were overpronators, which aligns with the research conducted by Menz et al. [15]. Additionally, military recruits are prone to experiencing excessive pronation, which can increase the likelihood of lower limb injuries. Thus, it is essential to consider footwear design and support mechanisms to address this issue effectively. Research by Lucas-Cuevas et al. [22] has emphasized the significance of footwear characteristics in managing overpronation. Their findings suggest that shoes with appropriate arch support and motion control features can help reduce overpronation and mitigate associated risks. Additionally, a study by Deepashini et al. [23] examined the effects of different shoe types on pronation during running. Their research demonstrated that stability shoes with reinforced arch support can effectively reduce excessive pronation, making them a potential solution for individuals with overpronation tendencies. Therefore, military cadet training programs should consider incorporating assessments of pronation patterns and providing appropriate footwear options to reduce foot pronation-related injury risks such as plantar fasciitis, shin splints, and Achilles tendonitis [16,24,25].

Lastly, the prevalence of a positive Trendelenburg's test in 93% of cadets is concerning as it suggests a high incidence of hip abductor weakness or dysfunction. This finding is consistent with studies highlighting the importance of addressing hip muscle strength in military training programs to reduce the risk of hip and lower back injuries [26]. Although there is a lack of direct studies on military cadets, research in athletic populations and military personnel has shown promising results regarding the use of corrective exercises to address hip abductor weaknesses and improve hip stability. Distefano et al. [27] studied the effects of a hip abduction strengthening program on female collegiate athletes. After implementing a targeted exercise regimen, they reported significant improvements in hip abduction strength and reductions in Trendelenburg sign prevalence. Similarly, Wilson et al. [28] investigated the impact of a 6-week hip strengthening program on hip muscle strength and functional performance in military personnel. Research by Rathleff et al. [29] also emphasised the importance of hip muscle strength in military personnel and suggested that targeted exercises could enhance hip stability and potentially reduce injury risks. However, the study did not specifically focus on Trendelenburg's test.

Lower Limb Flexibility

The results of the ankle clearing test indicated that a substantial proportion of the officer cadets (70%) exhibited good lower limb flexibility by reaching both feet beyond the designated zero line. In contrast, 22% of cadets scored behind on one side of their foot, and 8% reached behind the zero line for both feet. This indicates some variability in lower limb flexibility within the participants. These findings emphasize the importance of considering individual differences in flexibility during training and injury prevention programs.

On the other hand, the assessment of ITB tightness in this study revealed that nearly half of the cadets (47%) displayed no signs of ITB tightness. However, it is important to note that the ITB can become tight or overused in some individuals during training, potentially leading to knee and hip issues [20]. The occurrence of one side being positive for ITB tightness in 24% of participants suggests that unilateral ITB issues are not uncommon and may require targeted interventions and rehabilitation [30]. Moreover, the finding that 29% of cadets had both sides positive for ITB tightness underscores the importance of monitoring and addressing bilateral ITB tightness in military training programs to reduce the risk of injuries related to the lower extremities [31].

Lower Limb Characteristics vs. Flexibility and Injury Incidence

Our results indicated that only foot pronation significantly influenced the officer cadets' ITB flexibility, underscoring the intricate relationship between the two. Pronation is a dynamic foot motion involving complex interactions between the arch, ankle, and lower leg muscles [16]. This result is consistent with research conducted by Mucha et al. [20], which suggests that individuals with overpronation tendencies are more likely to experience increased tension and tightness in the ITB. Overpronation can result in internal rotation of the tibia, leading to altered biomechanics that may contribute to ITB issues. Furthermore, a study by Hreljac et al. [32] examined the influence of foot pronation on lower extremity kinematics during running. They found that overpronation was associated with increased knee abduction and internal rotation, potentially leading to ITB tightness and related problems. The impact of foot pronation on ITB flexibility has practical implications for military recruit training programs. This suggests that individuals with overpronation tendencies may benefit from targeted interventions to address foot mechanics and ITB flexibility. Such interventions might include orthotic inserts for arch support [16] and specific flexibility exercises to enhance ITB flexibility [33].

Lower Limb Flexibility vs. Injury Incidence

In this study, ITB flexibility was found to significantly affect injury incidence. This finding aligns with the growing recognition of the role of the ITB in various lower limb injuries, especially in activities involving repetitive knee motion [20,34]. Limited ITB flexibility can increase tension and tightness in the band, potentially contributing to ITB syndrome and related injuries [34]. This condition is characterized by pain on the lateral aspect of the knee and is often associated with activities that involve knee flexion and extension, such as running and marching during military training [35]. Recent studies have shown that incorporating targeted flexibility exercises into military training programs can effectively improve ITB flexibility and reduce the risk of associated injuries. For instance, a study by Borges et al. [36] demonstrated that structured flexibility training programs such as static stretching and proprioceptive neuromuscular facilitation significantly increased ITB flexibility, thereby potentially reducing the risk of ITB-related issues. Additionally, a study by Brown et al. [33] highlighted the benefits of incorporating dynamic stretching routines targeting the ITB. Their findings suggested that regular inclusion of dynamic stretching exercises can contribute to improved ITB flexibility and overall lower limb function. Furthermore, Akima et al. [30] looked at the impact of short-duration spaceflight on thigh and leg muscle volume, emphasizing the role of flexibility exercises in maintaining muscle function. While these studies were not specific to the military population, they highlighted the importance of comprehensive flexibility training to address tightness in relevant muscle groups, including the ITB.

5.0 CONCLUSION

The results obtained in this study offered valuable insights into the prevalence of various foot types, knee alignment, foot pronation, hip functions, lower limb flexibility, and the incidence of injuries among officer cadets during their cadet training, which cannot be overstated as they underpin the factors influencing injury risk and the foundation for enhancing injury prevention strategies within military cadet training programs. Overpronation was associated with increased tension in the ITB, highlighting the need to consider biomechanical intervention within the lower extremities. The implications of these findings are far-reaching, suggesting that military cadet training programs can benefit from tailored interventions aimed at improving ITB flexibility and addressing foot pronation issues, such as flexibility exercises and dynamic stretching routines. This could be instrumental in reducing the incidence of ITB-related injuries and MSK injuries in general, thus enhancing the officer cadets' performance during training.

However, further research is warranted to investigate the impact of targeted interventions in reducing MSK injury occurrence in the military population.

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Optimising Communications Information Systems Support on Operations: How Can 5G Network Boost Military Capabilities?

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A B S T R A C T

Similar to other organizations, the military's reliance on wireless connectivity is steadily increasing. The organization's use of technology has also grown as the world becomes more technologically reliant. This trend can be attributed to the ever-increasing demand for information, enabling the military to enhance its situational awareness and operational effectiveness on the ground. In today's dynamic and rapidly changing environments, the demand for seamless and dependable wireless communication has become a crucial factor, allowing military personnel to stay informed and make quick decisions. This pressing requirement prompted the military to implement cutting-edge wireless technologies, pushing the boundaries of innovation and efficiency to meet the demands of modern warfare. This study explores the possibilities of 5G application within the military landscape, focusing on its operations. The research reveals that militaries require a faster network and addresses the spectrum management aspect of 5G in a military context. Another aspect this paper explores is the possibility of 5G's infrastructure sharing with the commercial network. It delves into potential issues that may arise if implemented. This study presents an opportunity for future research on 5G before its actual application in the military.

Keywords:

5G, Wireless, Operations, Spectrum Management, Security, Military.

1.0 INTRODUCTION

Technological demand for faster connection and strong support derives the importance of implementing the fifth generation (5G) of wireless communication. Compared to its predecessor, 5G is slightly different due to its novel features such as interconnecting people, and controlling devices, objects, and machines. 5G provides a high data rate, improved quality of service (QoS), low latency, high coverage, high reliability, and economically affordable services [1]. With a very low latency rate, real-time interaction is possible, which enables procedures not possible with the generation prior to this. Procedures such as remote surgery and vehicle-to-vehicle (V2V) communication are now possible. For the military, with what is mentioned above, subjects such as 'unmanned vehicles', transmitting high-definition video for situational awareness, and reliable communication networks will become more prominent.

This has created a plethora of new technological options that could be utilised by the military, but there will be obstacles along the path. When new technology is introduced to a particular field, it presents management with a unique set of benefits and challenges. It could be useful in a variety of methods for military operations. Having 5G as the backbone of their network system, for instance, could improve a number of capabilities, such as enabling new command and control (C2) methods [2]. However, a number of obstacles will also arise, as this system will require a great deal of modification and adaptation prior to becoming effective. Military must have a comprehensive plan for adopting 5G as part of their wireless communication network, as it will tremendously benefit them in many ways, including their operations.

As 5G is a relatively new technology, there are very few studies on how it can improve overall operations, let alone how it can improve military capabilities. Due to the sensitivity of the subject, it is very rarely published. To move forward, however, military must determine how advantageous it is to have 5G as the backbone of their system, how it will impact their operations, and whether they require this form of wireless network at this time.

In an operation, military as a unit is connected to multiple wireless networks, and all of its sub-units are well-connected to one another but with a bandwidth that is normally extremely low. To explain military's wireless network in a nutshell, in general. military uses an encrypted Very High-Frequency Radio (VHF) to operate, with High-Frequency Radio (HF) as a backup in case the VHF radio fails; both of these radio networks are digital combat net radio. There are additional wireless networks that could be used, but these two are the primary networks for operational purposes. Military as a unit is securely connected, but the digital combat net radio capability only provides a low bandwidth wireless connection; this has hindered military's ability to receive and transmit information with the ground unit in numerous ways. Given their job requirements, this is quite alarming. Military must have access to a quick and dependable wireless network in order to operate efficiently. By having this capability, they will be able to receive and transmit data much more efficiently across the network, this will enable them to do their operation much more efficiently besides enabling a lot further advancement.

This research revolves around three primary questions aimed at understanding the strategic integration of 5G technology within military operations. These inquiries include investigating how the military plans to leverage 5G in their future operations, determining the optimal frequency for military use to harness the full potential of 5G technology, and exploring whether the military should establish its independent 5G network or collaborate with the commercial sector. The paper seeks to elucidate how 5G can enhance military operations by serving as a key component of their wireless networks, emphasizing the analysis of 5G's contributions to network efficiency. The study also delves into identifying the most suitable frequency for military 5G operations and evaluates the feasibility of sharing infrastructure with the commercial network from a security standpoint. To achieve these objectives, the research will focus on identifying 5G usage within future military operations, pinpointing the most suitable frequency for military use, and outlining potential security challenges associated with sharing infrastructure and network resources with the commercial sector.

2.0 LITERATURE REVIEW

Rajiv Shah argues that the applications of 5G networks are still largely unknown [3], as this technology is relatively new. Giles Ebbutt's report does indicate that 5G is being considered for military use in the future [4], but further research is required to determine whether this is feasible. Thus, how it will be utilised is still unclear to many organisations.

The second gap is concerned with the military. What frequency portion of the electromagnetic spectrum will be allocated to military? As a result of this, the network concept and equipment to be acquired in the future will be determined. To give military the upper hand in determining which form of 5G frequency is best suited for future use, they need to identify with network regulatory provider which portion of the available spectrum is best suited for them.

The final gap is relevant to security. As mentioned earlier, for the current 5G standard, it is now possible for military to operate within the commercial network, as this option will be more cost-effective and theoretically feasible than having their own network, which will be costlier to implement even for the military standard. Never before has a commercial network been used as the principal means of communication in an operation. Therefore, it must conduct research to confirm the security of 5G.

In the next section contains information on 5G in general as of the time this paper was written, as well as the potential benefits it could provide to the military once 5G is integrated into their network and how it can aid operations in general. In addition, it identifies the most probable obstacles that military will encounter.

5G Network

Rajiv Shah describes the 'real' 5G as made up of three key components, in simple terms; Faster mobile broadband speeds or extreme mobile broadband (eMBB), Ultra-reliable low-latency communications (URLLC), and Massive machine-to-machine communications (eMTC) [3]. It is widely accepted that 5G is made up of these three main components so far. This is shown in **Figure 1** below.

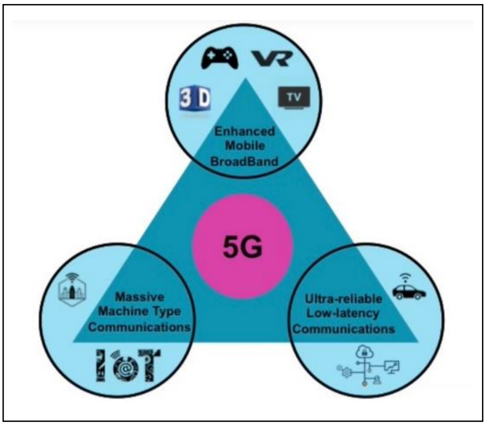

Figure 1. 5G three main components.

Several studies in the literature indicate that 5G will provide all of these services, but Rajiv Shah argues that no one really knows what 5G networks will be used for, which could include the military because these networks are still being tested by many organisations, including the United States [3], which has one of the largest military forces in the world.

However, Giles Ebbutt suggests in his report that 5G is being considered for military use in the future. In his report, he stated that the Nokia White Paper identifies multiple ways in which 5G offers advantages for military applications. For command-and-control (C2), 5G provides the required secure bandwidth to "consolidate multiple layers of information coming from many different domains, including video, for enhanced situational awareness and real-time operations monitoring"10. Therefore, there will be a variety of ways in which 5G could enhance the defence network and consequently improve its operation.

The installation of 5G technology could significantly enhance the operation of military. Currently, for wireless network, Combat Net Radio (CNR) and Digital Trunking Radio System (DTRS) are some of their primary communication channels; however, switching to 5G could provide a significant improvement. Nevertheless, before actually committing to this system, military must devise a comprehensive plan for how it will be utilised, regardless of whether it is necessary. To incorporate this newly developed technology, research is required. In addition, challenges are imminent in its integration.

5G Frequency Management & Sharing 5G Infrastructure

The 5G frequency band is segmented into High band or Millimeter-wave (MMW), Mid band, and Low band. Sayler indicated in his report how crucial it is for an organisation like the military to have a frequency management plan that is compatible with the commercial frequency plan. In the United States, the Department of Defence (DOD) holds a significant amount of 5G frequencies, preventing the commercial sector from exploring this option.

While, sharing 5G infrastructure is one of the possibilities that are accessible for military. Although this is conceivable, Amanda Toman noted that even though 5G might potentially operate within the commercial network, security vulnerabilities need to be addressed and security add-ons need to be obtained. When it comes to sharing infrastructure with the commercial side, the stakeholders in the operation are aware that this can make matters more complicated from a security standpoint. Managing it will be very crucial, which is in line with what Amanda Toman said, weaknesses need to be detected, and additional security needs to be set.

Possible 5G Challenges on Military

As mentioned, Nokia has identified multiple ways in which 5G offers advantages for military applications, but this also comes with challenges. For US DOD, one of the examples will be from the U.S. Navy, they leverage 5G capabilities to automate and digitize naval supply chain operations to increase supply chain efficiency by leveraging the newest technologies for automation such as autonomous mobile robotics and real-time asset visibility [5]. But challenges are inevitable, frequency allocation is one of them. For the DOD, they are facing challenges in holding to a frequency band between 3.1-3.45 GHz considered to be a useful 5G frequency. The US Defense Innovation Board (DIB) advised the DOD to consider sharing sub-6 spectrum with other agencies, to promote the rollout of 5G networks and the research and development of 5G technologies utilizing sub-6 band spectrum [6]. So even though it will offer advantages, frequency management could be identified as one of the challenges that the military could be facing.

Based on current trends, Sayler identified 5G technologies plan to use three segments of the electromagnetic spectrum: high band (also called millimeter wave, or MMW), which operates between around 24 and 300 GHz; mid-band, which operates between 1 GHz and 6 GHz; and low band, which operates below 1 GHz. Spectrum utilisation by military 5G will be one of the challenges that could be identified.

The second challenge for this new wireless network will be its security. With the current 5G standard, it is possible for the military to operate within the commercial network, according to Ebbutt. However, Amanda Toman (acting principal director of the 5G Future Generation Initiative at the U.S. Department of Defence) stated that security vulnerabilities must be identified and security add-ons must be acquired before 5G can operate within the commercial network. Military is familiar with the concept of conducting an operation with secure communication using a commercial network; commercial satellite phones have been used as one of the backup communications if the primary network is down. However, it has never been done to use a commercial network as the primary means of communication. Therefore, if 5G were to be implemented, could military take any steps to secure the security of its network?

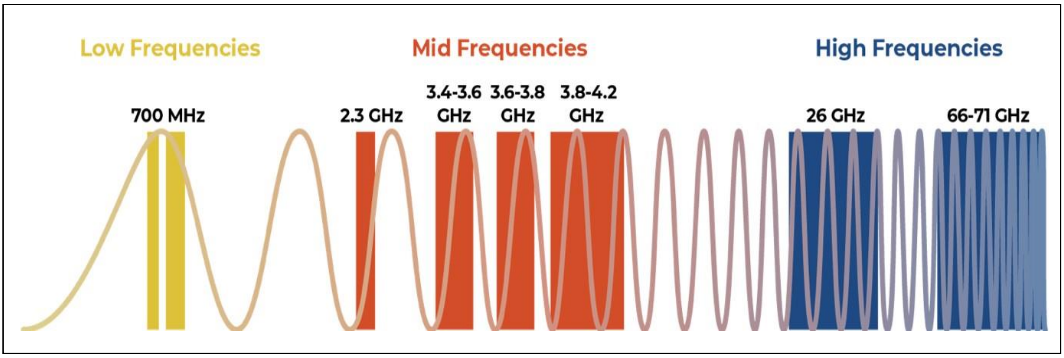

Figure 2. 5G frequency band.

3.0 METHODOLOGY

For this study, we conducted a bibliographic analysis on the topic of 5G deployment in the military. Our data collection method involved the use of qualitative secondary data from peer-reviewed journal articles. We searched the Scopus database using the keywords "Military" and "5G" and limited our search to articles published in peer-reviewed journals. The search returned 428 articles, which were analyzed using a bibliometric approach. Bibliometrics is a research method that uses statistical analysis to identify patterns and trends in a body of literature. We used bibliometric tools, such as VOS viewer, to identify key authors, institutions, and publications in the field, as well as to identify the most frequently used terms and themes. We analyzed the data using a qualitative approach, which involved identifying themes and patterns in the literature. The study conducted a thematic analysis, which involved identifying and categorizing common themes and concepts in the literature. We then analyzed these themes to identify key trends and patterns. Our analysis focused on identifying the benefits and challenges of 5G deployment in the military. The use of qualitative secondary data from a bibliographic analysis allowed us to identify key patterns and trends in the literature on 5G deployment in the military. By limiting our search to peer-reviewed journal articles, we were able to ensure the quality and relevance of our data. The use of bibliometrics allowed us to identify key authors, institutions, and publications in the field, as well as to identify the most frequently used terms and themes.

4.0 ANALYSIS

These works were analysed and compared to the current situation in the military. To answer the questions and accomplish the objectives of the study, pertinent data was gathered. A comprehensive literature review and bibliographic analysis were conducted to identify and review existing research on the application of 5G technology in military and defense contexts. This review helped establish the current state of knowledge, gaps in the literature, and potential areas where 5G can enhance communication and information systems for military operations. Then, the literature review was analyzed thematically to identify recurring themes, trends, and findings related to the integration of 5G technology in military operations. This analysis helped build a conceptual framework for understanding the potential impacts.

Figure 3 shows the bibliometric analysis of 428 articles. We conducted tracking on publications with the themes "Military" and "5G" broadly categorized into three research clusters. Each cluster is represented by a distinct color. The first research cluster for this theme is depicted in blue, predominantly addressing military applications, satellite communication systems, microwave antennas, and wireless communications. The second research cluster is represented by the color green, focusing on the 5G topic, particularly examining the quality of service within the context of military communication.

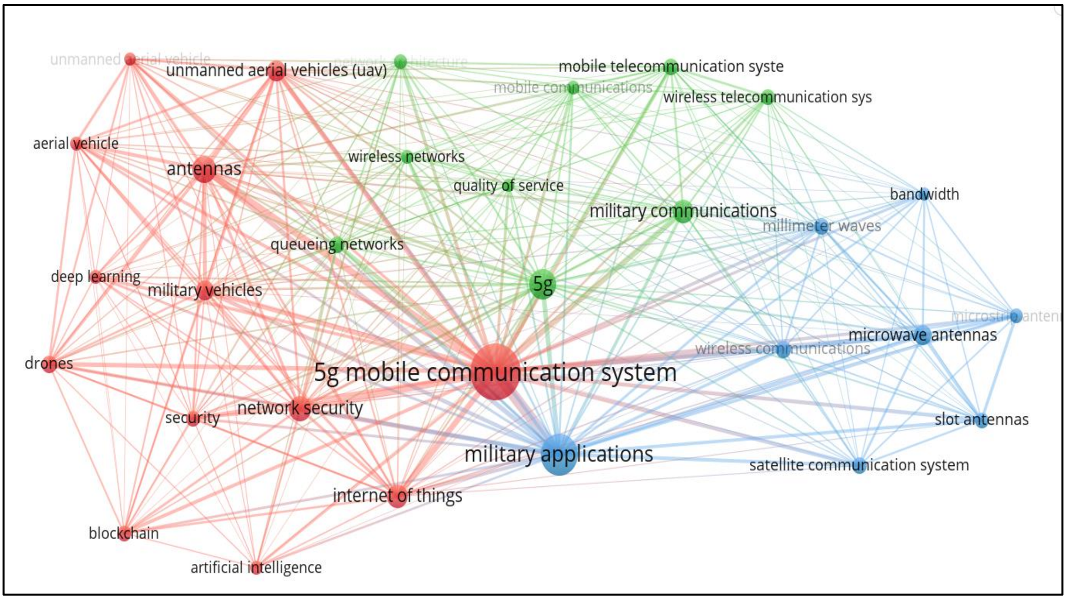

Figure 3. Bibliometric Analysis on military DAN 5G.

While, the extensively discussed research cluster for the topic of 5G in the military is depicted in the red cluster. Here, popular research topics revolve around the applications of 5G in Artificial Intelligence (AI), Internet of Things (IoT), military vehicles, deep learning, Unmanned Aerial Vehicles (UAVs), drones, and blockchain. Notably, the integration and planning of 5G in military operations have been relatively less explored.

The analysis reveals a concentration of literature on specific aspects of 5G in military contexts, with a noteworthy emphasis on emerging technologies and applications. This insight provides a valuable foundation for understanding the current landscape of research in the intersection of military operations and 5G technology deployment.

5.0 DISCUSSION

This section analyzes the considerations that the military needs to examine before formulating a strategy on how to integrate 5G into their network. This analysis is based on the data gathered as a result of the lack of planning for the usage of this network. To accomplish this and provide a solution to the research question, the paper will conduct a SWOT analysis to identify the strengths, weaknesses, opportunities, and threats associated with the implementation of 5G in military operations.

5G for Military

First, the paper going to discuss the “strength” of 5G. The introduction of 5G networks is groundbreaking. Its superior transmission rates, stability, and minimal latency are well-known characteristics [7]. However, what does it mean for military operation? There are many new initiatives on how 5G is going to be used; hence, the

US government announced $600 million in awards for 5G experimentation and testing at five U.S. military test sites [8]. Payne and Fowler believe that it has the potential to maximize US DOD hitting new heights in technological advancement, performance, and additional capabilities, based on the literature analysis revealed that 5G can help improve operations [9]. As the adoption of 5G is in early stage, a proper study needs to be done on this before actually deploying to it, especially military, if they decide in having its own 5G network. One way that military could use 5G is just by improving their sensor's connectivity.

The study also revealed that was brought up in relation to the weakness that 5G had on the operation was coverage by 5G. When looking at the locations where military will be conducting its operations, their fear is warranted. As was previously indicated, military is operating in both built-up and remote regions. The area of operation for the military extends from the built-up city to the more isolated or remote areas. Communication is one of the obstacles that must be overcome in order to accomplish this goal, which is partly caused by the absence of communication infrastructure that sometimes exists within their region of activity.

To develop a 5G plan, 5G network coverage must be developed covering military operating area. By comparing the data, military should be able to determine whether 5G equipment is worth the investment. Therefore, the 5G plan must consider the coverage mapping for their operational area.

For "opportunity", like what is being mentioned by Payne and Fowler, 5G has the potential to maximize technological advancement. One example will be during the interview with the operational stakeholder, the participant mentioned AI as part of planning assistance that could be enabled by having 5G as their network. But, up until now, the US has been struggling to launch its AI platform, Joint All Domain Command and Control (JADC2) [10]. To build a comprehensive plan, military needs to consider and include all possible factors and scenarios.

Options of Having Own 5G Network

As for "threat", one of the significant factors will be the cost of building and maintaining a 5G network. If military wants to commit to this it must invest in all network domains, including spectrum, radio access network (RAN) infrastructure, transmission, and core networks [11]. This will cost a lot of money, an exact cost to this cannot be determined now, as it will be influenced by the structure of the network, such as the area that military planning to cover, what 5G speed they envision to have in their area of operation and many more. On top of this, the current wireless infrastructure that military is using is not a 4G network, which could be upgraded easily into 5G. So, if military ever decides to have its own network, a full study needs to be done including the full infrastructure upgrade. The security factor is an essential "threat" that could be identified. This pertains to the proposal to share 5G infrastructure with the commercial network.

Another "threat" that is significant will be the frequency management of 5G. The military will not be given an advantage and priority on their frequency management plan, they will be treated like any other agency if they were to acquire any frequency for the usage, which includes 5G.

Without these priorities, the military must make use of what frequency is left. In the case of the US, the DOD holds large portions of the usable spectrum (5G), this enables them to operate at a frequency advantage to them in defending their country.

In the event of a future conflict, the victor will be the side that best controls and manages the electromagnetic spectrum [12]. Furthermore, by determining what frequency band they going to use, it will also ensure no interference with other agency's frequency in the future, as interference has the potential to jeopardize an operation. So military needs to ensure that a plan of 5G integration needs to include the frequency band that they going to be operating on, to give them an advantage in EW and to prevent future frequency interference.

6.0 RECOMMENDATIONS

Several recommendations could be derived from the findings of this research. The first recommendation will be for military to develop a 5G integration plan as soon as possible. 5G is the next step in the evolution of wireless communications, expanding on the progress made by 4G LTE. If military wanted to advance on its wireless network, it had to develop an integration plan.

According to the findings, it is recommended that military detail how they intend to utilise this 5G network in their plans. To accomplish this, they must have a clear roadmap of where to deploy or install this network in an operation, as coverage was the primary concern obtained from the interview. If military ever decide to commit to this, there are already available solutions that meet this need, as evidenced by a number of published works. One of them suggested that a 5G system utilising 3rd Generation Partnership Project (3GPP) technologies would provide a cost-effective, high- capacity, and long-range solution. This system employs lofty towers and high-power base stations and operates in the mid-band (3.5GHz) [14]. This case study is conducted in Brazil, which is a much larger country with a much larger rural consumer base, making the concept much more feasible. As indicated previously, the mid-band (3.5GHz) mentioned is already reserved for Fixed Satellite Services (FSS) downlink [15]. To effectively utilise this, military must collaborate with 5G Task force to develop a superior solution. Thus, additional negotiations and research are required.

In reference to the frequency band, the strategy that military needs to build must also incorporate a band that will provide them with a competitive edge. Since the introduction of radio communications during the First World War, a variety of technological advancements in information transmission have brought significant military utility. These advancements include the capability to transmit more information, more quickly, and over greater distances securely [16]. These advancements highlight how important it is for the military to have control over the frequency that they are using. Therefore, military needs to establish a strategy that includes the 5G frequency that they will most likely be operating on in order to make full use of 5G technology. This will help them to defend the country more effectively.

As for the infrastructure, the option of sharing it with a commercial network is a more feasible option. As discussed earlier, it is possible for the military to share, but with proper precautions and measures in place. Stakeholders need to discuss developing a policy that takes advantage of 5G and yet safe to use. By having this policy, they could start thinking of collaborating with Telco providers. A new deployment paradigm for mobile systems based on network resource sharing enhances the business case for wider coverage [17]. By negotiating with Telco providers, military could highlight its blind spot during its urban operations and ask for help from telco to provide coverage within that area. And vice versa, telco could ask help from military to provide them coverage in the rural area, where their communications tower is not present. This collaboration could benefit each other. So military needs to include this in their plan as well to ensure better usage of 5G technology in their operation.

7.0 FUTURE DIRECTION

For future research, a few suggestions could be made to improve the results. The first one will be on analysing which frequency of 5G military should be operating on. Future study could look at all military assets that are using wireless networks and identify any 5G ready equipment. After accumulating all this equipment, they could categorise which frequency all this 5G equipment is operating on. By doing this, military could identify which frequency they need to reserve, to support the point of which 5G frequency they be most suitable for them.

The second suggestion will be to look at policy on 5G. By looking at policy, then the paper could know the possibilities of sharing the same infrastructure with a commercial network. Furthermore, by doing this, the paper could identify which measures need to be taken for the process to take place, and then study whether it is possible for 5G technology.

The third and final suggestion will be to look at the Telco's 5G coverage plan and compare it to where military's operation area. By comparing this, the study will be able to know the reliability of 5G network in military's operation area. With this information, the study would be able to identify how 5G will be used by military in the future and whether it is worth it to build 5G infrastructure.

8.0 CONCLUSION

It is inevitable that military will incorporate 5G into its network, as it will be necessary for all organisations to function effectively in the future and keep up with the changes in the world. Integrating 5G into their network could further enhance their connectivity. Multiple capabilities will benefit from a quicker connection and high bandwidth wireless connection in the present and future. The study highlighted military needs to develop a 5G integration plan, to enable them to fully utilise 5G technology in their communication system. It also points out that lack of a plan has also shown indecision on which frequency they are most likely to be operating on, without knowing which 5G frequency, this may lead them to have a frequency that is not suitable for their operation. And this can lead to future frequency interference that has the potential crippling an operation, which can lead to a disaster. Furthermore, military needs to have control of the spectrum to allow them to have an edge in the field of EW, which is vital in determining conflict. Finally, this study also shows that there are possibilities for military to share 5G infrastructure with the commercial side. With proper management and measures, top with the policy that is developed by all stakeholders, sharing the infrastructure should be in consideration as for the cost of building the infrastructure, it will be greatly reduced. Collaboration with Telco is a must in order to achieve this. Moreover, by collaborating with them, the military can solve the coverage issue. By doing this, military operations can benefit from 5G technology.

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Prevalence of Self-Reported Work-Related Injuries (WRI) and Their Associated Risk Factors Among the Royal Brunei Armed Forces (RBAF) and Ministry of Defence (MINDEF) Military Personnel

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ABSTRACT

The purpose of this study was to assess the prevalence of self-reported work-related injuries (WRI) and their associated risk factors among RBAF and MINDEF military personnel. This study sought to provide valuable insights to help inform injury prevention planning and targeted intervention efforts. Data collection was conducted through an online cross-sectional survey from May to July 2023, focusing on participants' demographics, health behaviours, and injury history over the past 12 months. Descriptive statistics were reported and factor associated with injuries were determined using multiple logistic regression. In total, 508 military personnel participated in the study. The results showed that 71.3% of participants experienced at least one work-related injury within the past 12 months. Predominantly, these injuries affected the lower extremities and lower back, with the knee (36.2%), lower back (25.4%), and foot (24.9%) being the most commonly injured areas. Common injury types included strain (25.1%) and sprain/twisting (22.7%). The leading injury mechanisms were overuse or repetitive actions (82.9%), single twisting or overextension (14.6%), and the rapid onset of activity during physical training (11.3%). Notably, physical training activities such as running (49.7%) and weight-bearing activities (37.6%) were the leading activities at the time of injury. Factors associated with WRI included non-commissioned officer (NCO) status, poor sleep, unhealthy eating habits, tobacco use, and fatigue. Overall, the findings highlight the importance of addressing these risk factors and emphasise the need for targeted interventions to improve physical training practices and ensure safe execution of activities involving lifting, carrying, and moving objects. Apart from that, the insights gained from this study lay the foundation for future research focused on body areas that are susceptible to injury, enabling the continuous enhancement and development of more effective strategies to prevent injuries among military personnel.

Keywords:

Injuries, injury prevention, work-related, occupational, military, Brunei.

1.0 INTRODUCTION

As has been well-documented, military personnel are required to be at their physical best to perform their duties. However, work-related injuries, known to be prevalent among military populations, pose a significant threat to the overall mission readiness of both individual personnel and units. Injuries can have far-reaching impacts, affecting both financial aspects, such as the economic burden of medical, healthcare, and disability costs, and human resources, such as personnel unable to perform their duties optimally. In fact, injuries pose a greater threat to personnel health and troop readiness than any other medical issue. According to a study conducted by Molloy et al. (2020) injuries account for nearly 60% of soldiers on limited duty and contribute to 65% of soldiers who cannot deploy for medical reasons [1].

Over the past few decades, several military studies have attempted to study the extent of this issue, including identifying the common military injuries. Most of the studies have identified musculoskeletal conditions, injuries from training exercise (e.g., ankle fractures, sprains and strains of the knee), injuries caused by military equipment (e.g., finger fractures and open finger wounds), blast or firearm injuries, cold and hot weather injuries / illnesses, falls from heights, and crush injuries as the most prevalent injuries in the military [1,2,3]. Moreover, these studies have consistently shown that a substantial proportion of injuries occur during training and deployment [1,4,5]. To add, military researchers have identified various risk factors related to work-related injuries, including gender (with females being more susceptible), older age, lower educational level, inadequate prior physical activity, poor physical fitness, high body mass index (BMI) [1,3,6,7], stress, fatigue and smoking [3,8].

Despite extensive research on work-related injuries in the military from other countries, there has been relatively little-known research focusing on the prevalence, types, affected body areas, causes, severity, and associated risk factors among the Royal Brunei Armed Forces (RBAF) and Ministry of Defence (MINDEF) military personnel. This study, therefore, aimed to bridge this gap by investigating self-reported work-related injuries (i.e., injury incidence) and their associated risk factors, in order to help inform injury prevention planning and targeted intervention efforts to relevant units, such as the Medical Reception Station (MRS), Performance Optimisation Centre (POC) and Inspectorate Unit (IU). Research has shown that identifying prevalent injuries and related risk factors can shed light on crucial or key areas that need focus with regards to performance enhancement and injury prevention, identify the extent to which these military populations are affected and, monitor the trends of work-related injuries among RBAF and MINDEF military personnel.

Through this research, it is hoped that the findings can be utilised and make a significant contribution to enhancing the well-being and operational readiness of military personnel in RBAF and MINDEF. For instance, findings from this study can be utilised to assist RBAF in improving the RBAF Training Safety Regulation (TSR) and RBAF and MINDEF Occupational Health and Safety (OHS) guideline for work-related injuries prevention and reduction strategies. This can ultimately help reduce prevalence in the future, improve well-being and subsequently in enhancing the military readiness and performance, and ensuring operational success.

2.0 MATERIALS AND METHODS

This study was reviewed and approved by the Commander of RBAF. Prior to commencing the survey, participants were asked to read Participant Information Sheet and indicate they had and understood the information and agreed to proceed by making the appropriate selection on the online survey.

2.1 Study design

A quantitative exploratory study design was employed, utilising an online cross-sectional survey. The online survey was conducted between May and July 2023, through the use of MS SharePoint survey platform provided by the Defence Information Technology Unit (DITU). The survey questionnaire's link was distributed via closed WhatsApp groups associated with potential participants.

2.2 Study population

A convenience and purposive sampling method were used to obtain study samples. Participants were consisted of operational and non-operational male and female military personnel from various units from the Royal Brunei Land Force (RBLF), Royal Brunei Navy (RBN), Royal Brunei Air Force (RBAirF), Joint Force (JF), MINDEF, Special Force Regiment (SFR) and RBAF Training Institute (TI). No inclusion criteria were set for this study. However, the exclusion criteria were (i) recruits and (ii) officer cadets.

2.3 Data collection instrument and procedures

To collect the data, an online self-administered questionnaire was distributed to participants. The questionnaire incorporated a broad range of variables identified in the literature review as questions or factors related to work-related among military personnel. Majority of the questions primarily consist of pre-published, previously used and validated scales that were identified as being the most suitable and relevant for this study. The questionnaire was made available in both the Malay and English languages. To add, the questionnaire was culturally and linguistically modified and adapted for use among the Malay speaking participants. This was done in order to ease understanding and answering the items, as well as to capture appropriate experience in the targeted participants.

2.4 Measures

The survey collected the following information:

Demographic information: Five demographic items related to variables in this study were included: age, gender, highest educational level, weight and height (to calculate body mass index (BMI)).

Military service information: Four items were used to obtain details from participants about their military service: service branch, unit, rank, and service length.

Self-assessed health: Eleven items were used to gather information from participants about their health, including behavioural health factors (e.g., physical activity, overall dietary and sleep habits, tobacco use, stress, fatigue and anger). Physical activity was assessed by asking participants to indicate how many days they engage in physical activity (exercise or sport) per week and the duration of each session. Participants who engaged in at least 150 minutes of exercise per week were considered to have adequate exercise [1]. For dietary and sleep habits, participants were asked to indicate their overall healthy eating and sleep habits in the past 12 months. These responses were then recoded as binary variables, with the affirmative answers corresponding to "good" or "very good" responses. Similarly, for stress, fatigue and anger, participants were asked to report how often they had experienced these feelings in the past 12 months. These responses were also recoded as binary variables, with the affirmative answers corresponding to "often" or "very often" responses.

Injury information: Thirteen items were used to collect details from participants about their recent injuries: total number of injuries in the past 12 months, injured body areas, types of injuries, causes of injuries, and associated activities for the two most physically limiting injuries in the past 12 months. Participants were also asked about the impact of these injuries on their physical activity or job duties. Although participants were asked to report the total number of injuries they had experienced in the past 12 months (0, 1, 2, or 3 or more), the occurrence of any injury during the 12 months prior to the survey was coded as a binary variable (injured/non-injured). Injuries served as the variable against which other variables were regressed in univariate and multivariate analyses.

In this study, injury was defined as a physical injury caused either by: (a) single incident or accident (e.g., tripping and twisting ankle while marching, hit by or bumping into an object, injuries due to heat) or by (b) overuse of a body area (e.g., running long distances or repeatedly lifting/pulling/moving objects for job tasks or physical training) that have resulted in limited physical abilities and/or physical damage to the body.

2.5 Statistical analysis

Data analysis was conducted using IBM SPSS version 21 (SPSS Inc., IL, US). Descriptive statistics were used to present the survey data, where means and standard deviations were calculated for normally distributed continuous variables, and frequencies and percentages for categorical variables. For univariate and multivariate analyses, continuous variables were converted to categorical variables. Univariate logistic regression analyses provided unadjusted odds ratios and 95% confidence intervals (95% CIs). For variables with three or more categories, the reference parameter was usually chosen as the category with the lowest injury rate, to identify whether any comparatively high injury proportions existed.

Variables found to be significant in univariate logistic regression assessments of associations with injury during the past year ($P \leq 0.05$) were entered into a backward-stepwise multiple logistic regression analysis. If discrepancies were found in the univariate regression results between the significance of the overall variable and the significance of its individual levels of the variable, multivariate analyses were conducted with and without that variable included, and the final model with the best fit (as measured by the Cox and Snell R^2 statistic) was reported. Odd ratios and 95% CIs for variables remaining in the final multivariate models ($P \leq 0.05$) was reported.

3.0 RESULTS

3.1 Socio-demographic characteristics of participants

Of the six hundred and eleven (*N*=611) participants initially participated, 103 were excluded as they did not meet the eligibility criteria (i.e., currently a recruit or officer cadet), leaving a final sample size of 508 participants for data analysis. The socio-demographic characteristics of the participants are shown in **Table 1**.

Overall, most of the participants were 33 to 39 years of age (35.8%), male (87.0%), hold at least a high school 'O' level qualification or its equivalent (83.7%) and were overweight (52.8%), with a mean BMI of 25.5±3.48 kg/m^2.

Table 1. Socio-demographic characteristics of participants (*N*=508).

Variables	*N* (%)	Mean (SD)
Age (year)		33.0 (6.22)
19-25	59 (11.6)	
26-32	172 (33.9)	
33-39	182 (35.8)	
≥40	95 (18.7)	
Gender		
Male	442 (87.0)	
Female	66 (13.0)	
Highest Educational Level		
Primary Sch	2 (0.4)	
Secondary Sch	81 (15.9)	
'O' Level	231 (45.5)	
'A' Level	20 (3.9)	
Voc/Tech	109 (21.5)	
Bachelor	55 (10.8)	
Master	9 (1.8)	
PhD	1 (0.2)	
Body Mass Index (BMI)		25.5 (3.48)
BMI Index Status		
Underweight	1 (0.2)	
Normal weight	238 (46.9)	
Overweight	268 (52.8)	
Obese	1 (0.2)	

SD = Standard deviation; **Sch** = School; **Voc** = Vocational; **Tech** = Technical.

3.2 Participants' military service information

With regard to the participants' military service information (**Table 2**), the participants were largely consisted of RBLF personnel (48.2%), followed by RBAirF personnel (23.2%), SFR personnel (16.5%), MINDEF personnel (6.5%), RBN personnel (4.7%), JF personnel (0.6%) and RBAF TI (0.01%).

Overall, the most of the participants came from the following units: SFR (16.5%), Dental Services, RBLF (11.2%), Support Battalion (Sp Bn), RBLF (11.4%), and RBLF Headquarters (HQ) (9.4%), were non-commissioned officers (NCOs) (84.8%) and had 11 to 15 years of working experience in RBAF (23%).

Table 2. Participants' military service information (*N*=508).

Variable	*N* (%)
Service Branch	
Royal Brunei Land Force (RBLF)	245 (48.2)
Royal Brunei Navy (RBN)	24 (4.7)
Royal Brunei Air Force (RBAirF)	118 (23.2)
Joint Force (JF)	3 (0.6)
MINDEF	33 (6.5)
Special Force Regiment (SFR)	84 (16.5)
RBAF Training Institute	1 (0.2)

Variable	*N* (%)
Unit	
RBLF	
Headquarters (HQ)	48 (19.6)
First Battalion (1BN)	10 (4.1)
Second Battalion (2BN)	3 (1.2)
Third Battalion (3BN)	10 (4.1)
Support BN (Sp BN)	58 (23.7)
Combat Service Support (CSS)	26 (10.6)
Medical Reception Station (MRS)	24 (9.8)
Dental Services	57 (23.3)
Unspecified	8 (3.3)
RBN	
Headquarters	12 (50.0)
Fleet	5 (20.8)
Base	2 (8.3)
Support Service	2 (8.3)
Naval Training Centre	3 (12.5)
RBAirF	
Headquarters	14 (11.9)
No 1 Wing	9 (7.6)
No 2 Wing	17 (14.4)
No 3 Wing	10 (8.5)
No 4 Wing	32 (27.1)
No 5 Wing	31 (26.3)
No 7 Wing	5 (4.2)
MINDEF	
Minister of Defence II's Office	1 (3.0)
RBAF Secretariat Office	6 (18.2)
Directorate of Logistic	7 (21.2)
Directorate of Personnel	8 (24.2)
Performance Optimisation Centre (POC)	1 (3.0)
Royal Brunei Malay Reserve Regiment (RBMRR)	1 (3.0)
RBAF Defence Academy	6 (18.2)
RBAF Religious Directorate	3 (9.1)
RBAF TI	
Logistic	1 (100.0)

Variable	*N* (%)
Rank	
Pvt	73 (14.4)
LCpl	77 (15.2)
Cpl	111 (21.9)
Sgt	67 (13.2)
SSgt	59 (11.6)
WO II	29 (5.7)
WO I	15 (3.0)
Lt	39 (7.7)
Capt	18 (3.5)
Major	14 (2.8)
Lt Col	6 (1.2)
Service Length	
0-5	93 (18.3)
6-10	99 (19.5)
11-15	117 (23.0)
16-20	100 (19.7)
21-25	71 (14.0)
≥26	28 (5.5)

3.3 Injury incidences in the past 12 months

Table 3 displays the frequency of injured and non-injured personnel among the participants and the distribution of 1, 2, and 3 or more injuries for the past 12 months. Overall, a total of 71.3% of participants reported experiencing at least one work-related injury within the past 12 months; 27.8% reported one injury, 40.0% reported two, and 3.5 % reported three or more injuries. On average, 6.03 personnel were injured per 100 personnel per month.

Table 3. Frequency of injured and non-injured personnel among the participants and distribution (%) of 1, 2, and 3 or more injuries for the past 12 months (*N*=508 participants).

	N (%)	*N* (%)						
		RBLF *N*=245	**RBN *N*=24**	**RBAirF *N*=118**	**MINDEF *N*=33**	**SFR *N*=84**	**JF *N*=3**	**TI *N*=1**
Non-injured	146 (28.7)	74 (30.2)	6 (25.0)	34 (28.8)	13 (39.4)	17 (20.2)	1 (33.3)	1 (100.0)
Injured	362 (71.3)	171 (69.8)	18 (75.0)	84 (71.2)	20 (60.6)	67 (79.8)	2 (66.7)	0 (0.0)
No. of injuries								
1	141 (27.8)	71 (29.0)	9 (37.5)	34 (28.8)	10 (30.3)	17 (20.2)	0 (0.0)	0 (0.0)
2	203 (40.0)	90 (36.7)	9 (37.5)	46 (39.0)	9 (27.3)	47 (56.0)	2 (66.7)	0 (0.0)
3 or more	18 (3.5)	10 (4.1)	0 (0.0)	4 (3.4)	1 (3.0)	3 (3.6)	0 (0.0)	0 (0.0)

In terms of injury counts, participants were asked how many injuries they had experienced (0, 1, 2, or 3 or more). Assuming that all participants who answered 'three or more injuries' in the past 12 months (*N*=18) represented exactly three injuries, this makes up a total of 601 injuries. These findings indicate that, on average, there are an estimated 9.76 injuries per 100 personnel per month.

Table 4 below shows the frequencies of injured body areas, injury types, injury mechanisms and associated for each of the different Service branches and the overall study participants, as reported for the first- and second-most physically limiting injuries. While a variety of responses were collected for injury areas, types, mechanisms, and activities, only the most frequently reported for each are shown in **Table 4**, which lists at least the top five responses for each of the different Service branches and all study participants. Additional details about participants' first two injuries (*N*=583) are reported.

The results revealed that the injuries mainly affected the lower back and lower extremities, with the knee (36.2%), lower back (25.4%), and foot (24.9%) being the most commonly injured areas. Common injury types included strain (25.1%), sprain/twisting (22.7%), and arthritis (16.3%). The leading injury mechanisms were overuse or repetitive actions (82.9%), single twisting or overextension (14.6%), and the rapid onset of activity during physical training (11.3%). Notably, physical training activities such as running (49.7%),

Table 4. Frequencies of injured body areas, injury types, injury mechanisms and associated injury activities, as reported for the first- and second-most physically limiting injuries, for each Services and all participants (past 12 months, *N*=362 participants).

Variables	*Total* (%) (*N*=583 injuries)	RBLF (%) (*N*=271 injuries)	RBN (%) (*N*=27 injuries)	RBAirF (%) (*N*=134 injuries)	MINDEF (%) (*N*=30 injuries)	SFR (%) (*N*=117 injuries)	JF (%) (*N*=4 injuries)
Injured body area							
Knee	36.2	31.6	27.8	29.8	50.0	55.2	0.0
Back (lower)	25.4	31.6	22.2	23.8	10.0	17.9	0.0
Foot	24.9	33.9	11.1	14.3	30.0	16.4	50.0
Hip	09.9	06.4	11.1	08.3	15.0	19.4	0.0
Spine	07.7	05.3	11.1	08.3	0.0	14.9	0.0
Injury types							
Strain	25.1	28.7	38.9	22.6	25.0	14.9	50.0
Sprain or twisted	22.7	21.1	16.7	20.2	20.0	32.8	0.0
Arthritis	16.3	19.3	11.1	9.5	25.0	16.4	0.0
Spasm or cramp	13.3	14.0	5.6	11.9	15.0	11.9	100.0
Swollen	11.0	9.9	16.7	15.5	15.0	6.0	0.0
Injury mechanisms							
Overuse or repetitive movement / activity	82.9	93.0	44.4	81.0	75.0	73.1	50.0
Single twisting or overextension	14.6	11.1	16.7	15.5	10.0	23.9	0.0
Rapid onset of activity at the start of physical training	11.3	12.9	11.1	3.6	25.0	13.4	0.0
Contact (hit by or against) an object or surface	10.2	08.8	50.0	08.3	5.0	07.5	0.0
Falling onto an object or surface	8.0	4.7	0.0	10.7	10.0	14.9	0.0
Injury-associated activities							
Physical training (running)	49.7	53.2	38.9	33.3	70.0	55.2	100.0
Weight-bearing activity (wearing, carrying, pulling or moving heavy objects)	37.6	39.8	27.8	33.3	40.0	40.3	0.0
Physical training (weight-lifting)	15.7	10.5	11.1	13.1	10.0	35.8	0.0
Sports	11.9	10.5	11.1	19.0	20.0	4.5	0.0

Using, repairing or maintaining equipment	7.7	4.7	5.6	19.0	0.0	4.5	0.0

weight-bearing activities such as carrying, pulling or moving heavy objects (37.6%), and weight-lifting (15.7%) were the leading activities at the time of injury.

3.4 Factors associated with work-related injury

Table 5 presents the odds ratios and 95% CIs resulting from univariate logistic regression models. Being male, having poor eating and sleeping habits, using tobacco, and frequently feeling fatigued were identified as factors significantly associated with injury at the univariate level ($P \leq 0.05$). While military status was not found to be significantly associated with injury overall ($P = 0.054$), being a non-commissioned officer (NCO) appeared to be associated with an increased likelihood of injury when no other factors were considered ($P = 0.050$).

Age, education level, having a health problem, atypical BMI (i.e., underweight, overweight and obese), inadequate exercise, and frequently feeling stressed and angered were not observed to be significantly associated with injury overall ($P \geq 0.05$).

Potential risk factors for injuries identified in univariate models ($P \leq 0.05$) were entered into a backward-stepwise multiple logistic regression, and the results are presented in **Table 6**. The final model produced a Cox and Snell R^2 value of 0.332. The results indicated that military status (i.e., being NCO), having poor eating and sleeping habits, using tobacco and fatigued were significantly associated with injuries among the participants ($P \leq 0.05$). NCOs had nearly 2.5 times greater odds of injury compared to officers ($P = 0.013$). Participants who reported poor eating habits in the past 12 months had twice the odds of injury compared to those reporting good eating habits ($P < 0.001$), and those with poor sleeping habits had 3.26 times greater odds of injury compared to those with good sleeping habits ($P < 0.001$). Similarly, those who smoked tobacco had 1.65 times greater odds of injury compared to those who do not smoke ($P < 0.001$). Participants who reported feeling fatigued often or very often in the past 12 months had 3 times greater odds of injury compared to those who did not report these feelings ($P < 0.001$).

Additionally, interaction term analyses among the significant variables revealed that only poor sleeping habits and feeling fatigued were statistically significant. The results showed that those who reported having poor sleeping habits and frequently feeling fatigued had 12 times greater odds of injury ($P < 0.001$).

Table 5. Unadjusted association of demographic, health and self-reported behavioural health with injury among RBAF and MINDEF military personnel (*N*=508).

Variable	Variable category	*N* (%) Total	*N* (%) Injured	Injury OR (95% CI)	Category *P* value	Variable *P* value
Age	19-25	59 (11.6)	44 (74.6)	0.73 (0.36, 1.47)	0.372	0.386
	26-32	172 (33.9)	116 (67.4)	1.00		
	33-39	182 (35.8)	135 (74.2)	0.69 (0.41, 1.19)	0.182	
	≥40	95 (18.7)	67 (70.5)	0.63 (0.37, 1.07)	0.085	
Gender	**Male**	**442 (87.0)**	**319 (72.2)**	**1.53 (0.31, 1.91)**	**0.021**	**0.023**
	Female	66 (13.0)	43 (65.2)	1.00		
Military status	**NCO**	**431 (84.8)**	**315 (73.1)**	**1.60 (1.36, 2.00)**	**0.050**	0.054
	Officer	77 (15.2)	47 (61.0)	1.00		
Education level	High Sch, Voc &Tech	443 (87.2)	324 (73.1)	0.87 (0.22, 3.41)	0.838	0.087
	Bachelor	55 (10.8)	30 (54.5)	1.00		
	Master & PhD	10 (2.0)	7 (70.0)	1.68 (0.39, 7.18)	0.486	
Health Problem	Yes	99 (19.5)	58 (58.6)	1.00		0.328
	No	409 (80.5)	304 (74.3)	0.78 (0.47, 1.29)	0.334	
Atypical BMI	Yes	270 (53.1)	199 (73.7)	0.83 (0.57, 1.22)	0.351	0.351
	No	238 (46.9)	163 (68.5)	1.00		
Inadequate exercise	Yes	200 (39.4)	139 (69.5)	1.00		0.131
	No	308 (60.6)	223 (72.4)	0.74 (0.49, 1.10)	0.134	
Poor eating habits	**Yes**	**325 (64.0)**	**237 (72.9)**	**1.23 (1.09, 2.21)**	**<0.001**	**<0.001**
	No	183 (36.0)	125 (68.3)	1.00		
Poor sleeping habits	**Yes**	**330 (65.0)**	**245 (74.2)**	**1.76 (1.17, 2.39)**	**<0.001**	**<0.001**
	No	178 (35.0)	117 (65.7)	1.00		
Tobacco Use	**Yes**	**192 (37.8)**	**136 (71.5)**	**1.21 (0.13, 1.35)**	**<0.001**	**<0.001**
	No	316 (62.2)	226 (70.8)	1.00		
Stressed	Yes	119 (23.4)	79 (66.4)	1.00		0.518
	No	389 (76.6)	283 (72.8)	0.50 (0.31, 0.86)	0.518	
Fatigued	**Yes**	**169 (33.3)**	**125 (74.0)**	**1.46 (0.30, 1.72)**	**0.001**	**<0.001**
	No	339 (66.7)	237 (69.9)	1.00		
Angered	Yes	104 (20.5)	75 (72.1)	0.83 (0.31, 0.89)	0.180	0.130
	No	404 (79.5)	287 (71.0)	1.00		

Note. Significant factors ($p \leq 0.05$) are in bold. **OR** = Odds Ratio; **CI** = Confidence Interval; **NCO** - Non-commissioned Officer; **Sch** – School; **Voc** – Vocational; **Tech** – Technical.

Table 6. Adjusted factors associated with injury among RBAF and MINDEF military personnel (*N*=508).

Variables	Variable category	*N* (%) Total	*N* (%) Injured	Injury Adj. OR (95% CI)	Category *P* value	Variable *P* value
Military status	**NCO**	**431 (84.8)**	**315 (73.1)**	**2.34 (2.24, 5.37)**	**0.013**	**0.013**
	Officer	77 (15.2)	47 (61.0)	1.00		
Poor eating habits	**Yes**	**325 (64.0)**	**237 (72.9)**	**2.11 (2.07, 3.19)**	**<0.001**	**<0.001**
	No	183 (36.0)	125 (68.3)	1.00		
Poor sleeping habits	**Yes**	**330 (65.0)**	**245 (74.2)**	**3.26 (1.78, 5.96)**	**<0.001**	**<0.001**
	No	178 (35.0)	117 (65.7)	1.00		
Tobacco Use	**Yes**	**192 (37.8)**	**136 (71.5)**	**1.65 (0.09, 2.30)**	**<0.001**	**<0.001**
	No	316 (62.2)	226 (70.8)	1.00		
Fatigued	**Yes**	**169 (33.3)**	**125 (74.0)**	**3.07 (2.03, 3.19)**	**<0.001**	**<0.001**
	No	339 (66.7)	237 (69.9)	1.00		

3.4 Perceived severity and impact of the injuries

Table 7 presents the frequencies of perceived injury severity and its impact on their physical activity or job duties among different service branches and all study participants. The results indicate that the majority of injuries were perceived as moderate, accounting for 55.7% of all injuries, with a notable proportion was perceived as mild (30.0%). Severe injuries were less common (8.9%), while permanent injuries were reported in 5.3% of cases.

With regard to the impact of injuries on their physical activity or job duties, the data revealed that most had little impact (41.9%), followed by some impact (28.0%). In contrast, only 10.3% had a significant impact, and 17.3% had no impact at all. In addition, the data showed that a small percentage of injuries (2.6%), resulted in participants being unable to perform their assigned military duties.

4.0 DISCUSSION

The purpose of this study was to investigate the incidence of self-reported work-related injuries and their associated risk factors among RBAF and MINDEF military personnel. Identifying prevalent injuries and their related risk factors can help inform important areas for injury prevention and targeted interventions, which are essential for enhancing the well-being and operational readiness of military personnel in the RBAF and MINDEF.

Overall, within the past 12 months, 71.3% of participants reported experiencing at least one work-related injury. Among them, 27.8% reported one injury, 40.0% reported two, and 3.5 % reported three or more injuries. The injury incidence rate was 6.03 per 100 personnel per month, with an average rate of 9.76 injuries per 100 personnel per month. Notably, the injury rates reported in this study were considerably higher than those reported in

Table 7. Severity and impact of injuries on physical activity or job duties for the first- and second-most physically limiting injuries, for each Services and all participants (past 12 months, *N*=362 participants).

Variables	% Injuries (*N*=583 injuries)	% Injuries					
		RBLF (*N*=271 injuries)	RBN (*N*=27 injuries)	RBAirF (*N*=134 injuries)	MINDEF (*N*=30 injuries)	SFR (*N*=117 injuries)	JF (*N*=4 injuries)
***Severity* of the injury**							
Mild	30.0	32.8	37.0	32.1	23.3	21.4	25.0
Moderate	55.7	56.1	48.1	51.5	53.3	61.5	75.0
Severe	8.9	7.0	3.7	11.2	16.7	10.3	0.0
Permanent Injury	5.3	4.1	11.1	5.2	6.7	6.8	0.0
Impact of the injury							
No impact	17.3	20.7	14.8	12.7	23.3	12.8	50.0
Little impact	41.9	41.3	63.0	44.8	20.0	40.2	50.0
Some impact	28.0	28.4	22.2	23.9	33.3	32.5	0.0
Significant impact	10.3	7.7	0.0	13.4	20.0	12.8	0.0
Unable to perform military duties as assigned	2.6	1.8	0.0	5.2	3.3	1.7	0.0

in similar military studies, where variations in injury incidence rates among different countries were observed (approximately 4.1 and 5.6 per 100 persons per month in the US and Norwegian armies, respectively) [9,10]. The unexpectedly higher injury incidence rate in this study is likely be influenced by a combination of factors, including training and physical activity intensity, techniques employed, environmental conditions, as well as behavioural factors like fatigue and eating habits. Additionally, aspects related to sample size and representativeness may also be the contributing factors.

In regard to the injured body area, it was found that the lower back and lower extremities, specifically the knee and foot, were the most commonly self-reported body parts affected. This finding is consistent with findings from other studies involving military populations [10,11,12]. Furthermore, in this study, the predominant types of injury were strain and sprain/sprain, which is well supported in the literature [3,13]. These strains and sprains, typically observed in the lower back and extremities, are often result from activities, such as running, weight-bearing tasks (e.g., carrying, pulling, or moving heavy objects), and sports-related activities [13,14], as was supported by the current study.

Similarly, overuse/repetitive activities, overexertion, and rapid onset of activity during physical training were the most prevalent mechanisms of injuries among the participants, which concur with findings from previous studies [10,11]. This could be attributed to the demanding nature of training and physical activities, such as long-distance running and extended periods of physical exertion [3,7]. Additionally, the repetitive and medium/high-intensity nature of military activities or duties, which often involve performing similar activities or tasks without much diversification, can also contribute to these injuries [3,12]. Nevertheless, it should also be noted that insufficient recovery time [15], inadequate training, ineffective body mechanisms, or improper techniques [16] and the weight of equipment carried by personnel [17,18], which places additional stress on the body, especially the back, could also play a substantial role in injury occurrence.

Factors associated with injury were assessed for the overall study population, and results showed that most of the risk factors are typically modifiable (e.g., eating habits, sleeping habits and tobacco use) through awareness, education, clinical, or other interventions. Overall, factors associated with work-related injuries included NCO status, poor sleep, unhealthy eating habits, tobacco use, and fatigue. This finding is consistent with previous studies that reported a higher rate of injury among NCOs compared to officers [11,19]. NCOs often undergo more rigorous training and physical work, which exposes them to greater injury risks. In contrast, officers are generally in leadership positions, engaged in less physically demanding work, but focus more on mission planning and execution [11].

BMI, which often has a dependent association with eating habits, is frequently reported as an anthropometric measure independently associated with injury risk [20]. However, the findings in the current study have been equivocal. Although BMI was not associated with injury risk in either univariable or multivariable analyses in the current study, the result demonstrated a significant association between poor eating habits and injury. This discrepancy in research findings may be attributed to various factors, including confounding variables, sample characteristics (e.g., a small sample size lacking statistical power to detect a BMI association), measurement methods, and the specific mechanisms through which eating habits and BMI influence injury risk (e.g., the consumption of high-sugar, high-fat foods leading to fatigue and reduced physical performance, which can increase the risk of accidents or injuries). In summary, the relationship between BMI and injury risk is not as straightforward as that between eating habits and injury. These findings warrant further confirmation through additional studies and researchers should consider these factors when designing the studies.

Among the other risk factors explored, poor sleeping habits and fatigue are two of the most consistently cited lifestyle behaviours that increase the risk of injuries in the military [21,22]. Studies have indicated that poor sleeping habits and fatigue can increase the risk of injury by impairing cognitive function, reducing physical performance and alertness, and compromising physical and mental resilience. These effects can lead to accidents, poor decision-making, and heightened vulnerability, particularly in high-stress and physically demanding military settings [21,22].

Similarly, the results also indicated that tobacco use was a significant risk factor for injuries among these study populations. This finding is consistent with previous studies that have demonstrated a higher incidence of injury among military personnel who smoke tobacco [3,13].

Lastly, findings on the perceived severity and impact of injuries on physical activity or job duties are notable. The results indicate that the majority of injuries were perceived as moderate, with a significant portion classified as mild. This suggests that a substantial number of injuries, while not severe, still have implications for personnel.

Limitations and strengths of the study

The study has several important limitations. First, the observational and cross-sectional nature of this study limits the ability to assess causal relationships between the interested variables, given that injury, health and health behaviors were measured at the same time. Future research should consider longitudinal studies.

Second, findings were derived from a convenience sample with a relatively low sample size. This may limit the generalisability of the results. This study may be either over- or underestimated injury rates when compared to actual rates. In addition, it's worth noting that the majority of the study participants are non-infantry personnel, who typically engaged in moderate to less physically demanding tasks and theoretically posing a lower risk of injury compared to infantry personnel [6,23]. Despite this, the study revealed a considerably higher injury rate among the non-infantry personnel. Additionally, due to the unequal distribution of participants from different Services, meaningful comparisons could not be made. Future efforts should aim to include a larger portion of the population of interest.

Third, the reliance on self-report data gives rise to concerns about subjectivity and potential response bias. There is a high potential for recall bias, as participants were required to recall information from the past, and the extent to which recall bias influenced these findings is unknown.

Fourth, the study only included specific factors, and collecting additional details about working conditions may reveal other risk factors for injuries among the participants, such as shift length, occupational aerobic requirements, and occupational lifting requirements.

Despite these limitations, this study, however, can be considered an initial exploratory investigation of injury incidence and risk factors among RBAF and MINDEF military personnel. The findings can serve as a starting point for more research on this area.

5.0 CONCLUSION

In conclusion, this is the first exploratory study within the RBAF, that has provided valuable insights into the prevalence of injuries and the factors contributing to their occurrence. These insights help to inform injury prevention and targeted interventions aimed at enhancing the well-being and operational readiness of RBAF and MINDEF military personnel. For instance, interventions should encompass improvements in physical training practices, such as ensuring proper warm-up and emphasising proper techniques in order to reduce the risk of strains and sprains. Additionally, physical conditioning measures, like incorporating strength and flexibility training into military personnel's routines, should be considered. Ensuring the safe execution of activities involving lifting, carrying, and moving objects is also essential. Lastly, behavioral change interventions, such as education and awareness on nutrition, smoking cessation programs, and guidance on proper sleep hygiene, can play a pivotal role. Overall, these insights lay the foundation for future research aimed at reducing injury prevalence, improving well-being, enhancing military readiness and performance, and ensuring operational success.

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Evaluation of Nutritional Values in Herbal Cookies infused with *Murraya koenigii* and *Gnetum gnemon*

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A B S T R A C T

This study investigates the development of herbal cookies enriched with *Murraya koenigii* and *Gnetum gnemon*, aiming to explore their diverse nutritional compositions. Cookie formulation with 5 different ratios of the combination of the plant powder were prepared for this study (100%MK, 100%GG, 75%MK:25%GG, 50%MK:50%GG, 25%MK:75%GG). The herbal cookies were analysed for their nutritional values including energy in kCal, carbohydrates, protein, fats, minerals and moisture. The study revealed that cookies infused with 100% MK exhibited the highest energy 434.14 ± 7.34 kCal, highest protein 11.21 ± 0.00%, and lowest moisture content (2.56 ± 0.39%) compared to other cookies. Furthermore, 25%MK:75%GG cookies showed the highest carbohydrate content (84.98 ± 1.21%) and 50%MK:50%GG cookies with the highest mineral content (8.48 ± 3.13%). These findings underscore the adaptability of cookie formulations to cater to diverse dietary preferences and needs. Additionally, the incorporation of these functional and nutrient-rich cookies has the potential to meet the demand for portable, energy-dense provisions, particularly in challenging environments such as in military settings.

Keywords:

Murraya koenigii, *Gnetum gnemon*, herbal cookies, nutrition, energy, carbohydrate, protein, minerals.

1.0 INTRODUCTION

Cookies are one of the popular bakery products due to their convenience, ready to consume, low cost, prolonged shelf life and the ability to serve as a vehicle for important nutrients [1]. It can be easily fortified to provide necessary nutrition and instant energy for consumers. Herbs or spices with strong flavour and aroma are used in small quantity but impart high energy and lower calories in food product and able to supply the food product with essential minerals and nutrients [2]. By supplementing cookies with functional ingredients such as plant powder, can provide the cookies with additional benefits (such as antioxidant and minerals) to be delivered to the consumers [3,4].

Figure 1a. *Murraya koenigii*.

All-Purpose flour, butter and sugar are the basic ingredients for cookie formulation [5]. Whereas other ingredients are added for desired nutritional qualities and texture. *Murraya koenigii*, as shown in **Figure 1a**, is well-known as curry leaves, and belongs to the family *Rutaceae* and genus *Murraya*. Traditionally, the leaves were reported to be eaten raw for treating dysentery. A fine paste of *M. koenigii* leaves mixed with buttermilk can be taken on an empty stomach to treat stomach upsets [6], whereas fresh fruit juice of *M. koenigii* can help to relieve kidney pains [7]. *Gnetum gnemon* is another Brunei medicinal plant locally known as "*Bagu*" and commonly known as "*Melinjo*" in Indonesia and Malaysia, which is widely cultivated across Southeast Asia. The leaves and tender tips of *G. gnemon*, as shown in **Figure 1b**, are edible and can be consumed as vegetables, either boiled or eaten raw as salad or "*ulam*" in Southeast Asia [8].

Figure 1b. *Gnetum gnemon*.

The infusion of *M. koenigii* and *G. gnemon* as herbal cookies not only enriches the flavour but may also augment their nutritional value. The incorporation of functional and nutrient-rich cookies aligns seamlessly with the need for portable and energy-dense provisions in consumers. Thus, this study aims to comprehensively evaluate the nutritional content—covering energy in kCal, carbohydrates, protein, fats, minerals and moisture—of herbal cookies infused with *M. koenigii* and *G. gnemon*.

2.0 METHODOLOGY

2.1 Sample collection

Approximately 1 kg of *M. koenigii* (MK) leaf samples were collected from a local farm at Kg Madang, Berakas and 1 kg of *G. gnemon* (GG) leaves samples from local farms Kg Mata-Mata, Gadong and Kg Beribi, Gadong. Identification has been done by Dr Ferry Slik, Associate Professor and Curator of Herbarium and Botanical Garden, Universiti Brunei Darussalam, and voucher specimens for *M. koenigii* (AY-1124) and *G. gnemon* (AY-2417) were deposited in the Universiti Brunei Darussalam Herbarium (UBDH).

2.2 Preparation of bread flour

About 1 kg surplus of plain bread was collected from Mr Baker's Bakeshop at Gadong and Batu Bersurat. The bread chosen for this study was plain sourdough bread. The slices of bread were cut into smaller pieces approximately 3 cm by 3 cm and oven-dried at 80°C for 30 minutes, which are then ground into fine powder and stored in an air-tight container for food formulation.

2.3 Cookies formulation

Cookies formulation follows methods from previous studies with some modifications [9]. Different ratios of *M. koenigii* and *G. gnemon* leaves powder were infused to the cookies and weighed according to the ratios as stated in **Table 1**. The ingredients were hand mixed for 5 minutes to form a dough. Approximately 20 g of dough was weighed, and hand rolled into a cookie shape about 2 cm thick. Then placed on a baking tray and baked in oven at 180°C for 20 minutes.

Table 1. The number of ingredients of different samples of cookies. MK = *M. koenigii* and GG = *G. gnemon*.

Ingredients	Control	100% MK	100% GG	75% MK: 25% GG	50% MK: 50% GG	25% MK: 75% GG
All Purpose Flour (g)	50	50	50	50	50	50
Bread Flour (g)	50	50	50	50	50	50
Butter – Golden Churn(g)	60	60	60	60	60	60
Sugar (g)	40	40	40	40	40	40
Baking Powder (tsp)	½	½	½	½	½	½
Baking Soda (tsp)	½	½	½	½	½	½
MK powder (g)	-	1	-	0.75	0.50	0.25
GG powder (g)	-	-	1	0.25	0.50	0.75

2.4 Nutritional analysis

Energy [9]. Determination of energy was calculated as follows:

Energy = (4 x Fats) + (9 x Protein) + (4 x Carbohydrates)

Total Carbohydrates [10]. Carbohydrate content was calculated as follows:

Carbohydrate Content = 100 - (Moisture + Ash + Crude fat + Protein)

Crude Protein Content [11]. Saline solution (8.5 g/L) was used as the protein standard. 3 ml of Biuret reagent was added to 1 ml of cookie sample and 2 ml of saline solution. The mixture was incubated in at room temperature for 30 minutes. The absorbance was measured at 540 nm. The result was obtained from a standard curve.

Crude Fats Content [12]. 2 g of dried cookie sample was extracted using Soxhlet apparatus with petroleum ether (40–60 °C) for about 6 hours. After 6 hours, the flask was weighed and transferred to a rotary evaporator to remove petroleum ether from the fats sample. The flask was re-weighed to obtain the final weight.

Mineral Content [9]. 2 g of cookie sample was weighed in a crucible and placed in a muffle furnace for 3 hours at 500 °C. After 3 hours, the crucible was allowed to cool down for 10 minutes at room temperature and another 15 minutes in a desiccator. The crucible was then re-weighed. Total ash content was calculated as follows:

Total Ash Content = (Final Weight - Crucible Weight) / Sample x 100

Moisture Content. Total Moisture Content was measured using Moisture Analyser. 1 g of dried sample powder was placed on the balance of the moisture analyzer. The quick mode was selected to measure the moisture in the sample. After 2–3 minutes, moisture content percentage and temperature were displayed.

Statistical Analysis. Data were presented as mean ± standard deviation. Statistical significance was determined using One-Way ANOVA in Microsoft Excel where the p value less than 0.05 ($p<0.05$) was considered as statistically significant.

3.0 RESULTS AND DISCUSSION

Figure 2 shows the cookies samples used in this study. There are 6 different samples following their formulation and ratio of MK and GG: Control (no plant powder), 100% MK, 100% GG, 75%MK:25%GG, 50%MK:50%GG and 25%MK:75%GG. All six cookie samples were analysed for their nutritional analysis including energy in kCal, carbohydrates, protein, fats, minerals and moisture, as shown in **Table 2**.

The analysis of the six cookie samples reveals significant variations in their nutritional compositions. Particularly, the 100% MK cookies stand out with the highest energy content of 434.14 ± 7.34 kCal. Additionally, it demonstrates the highest protein concentration at 11.21 ± 0.00%, indicating a potentially favourable protein source for consumers. Moreover, these cookies exhibit the lowest moisture content among the samples, with a minimal 2.56 ± 0.39%, suggesting enhanced shelf stability. This information underscores the significance of the *M. koenigii* infusion in influencing the nutritional attributes of the cookies. The higher energy and protein

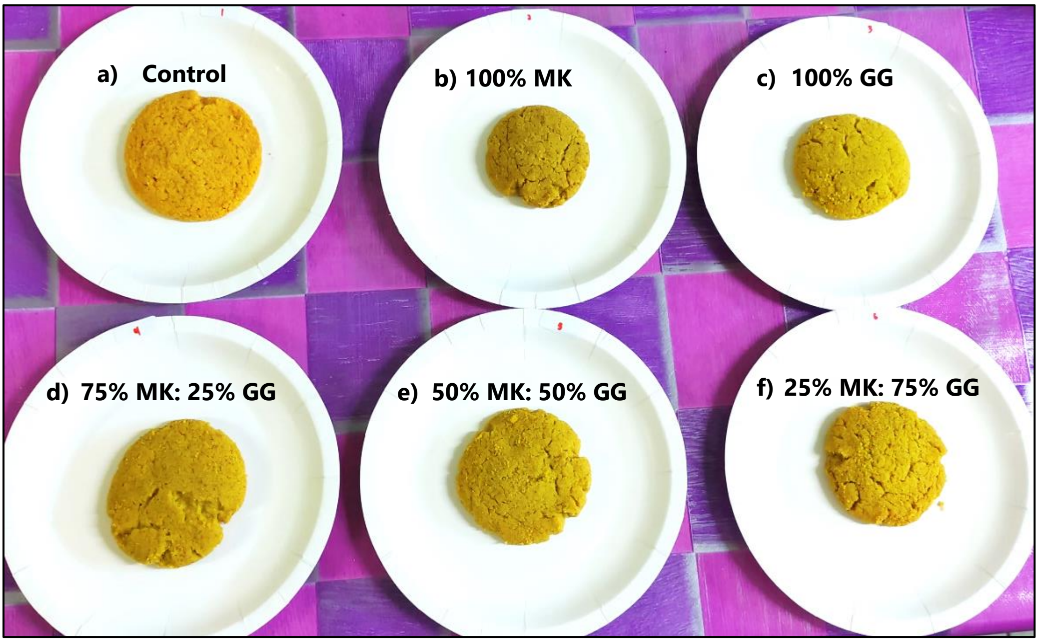

Figure 2: Six cookie samples were prepared for nutritional analysis.

levels, coupled with lower moisture content, contribute to the overall appeal of the 100% MK cookies, potentially meeting consumer preferences for both taste and nutritional benefits.

Furthermore, the 25%MK:75%GG cookies exhibit the highest carbohydrate content (84.98 ± 1.21%) among the cookie samples, suggesting a formulation that could provide a substantial source of energy. This composition may appeal to individuals seeking a quick and efficient energy boost.

Conversely, the 50%MK:50%GG cookies showcase the highest mineral content of 8.48 ± 3.13%. This particular blend indicates a well-balanced incorporation of *M. koenigii* and *G. gnemon*, offering a potential source of essential minerals. The synergy between these herbal ingredients appears to contribute positively to the mineral composition of the cookies, presenting a balanced nutritional profile.

Table 2. Nutritional analysis of six different cookie samples. **Bold** indicates highest value and underline indicates lowest value.

Parameters	Control	100% MK	100% GG	75% MK: 25% GG	50% MK: 50% GG	25% MK: 75% GG
Energy (kCal)	413.58±9.28	**434.14± 7.34**	405.08±8.19	417.84±0.62	393.95±14.39	410.38±6.01
Carbo-hydrate (%)	79.28 ± 2.34	79.8 ± 1.78	82.77 ±1.31	81.86 ± 1.83	76.23 ± 2.67	**84.98 ± 1.21**
Protein (%)	7.81 ± 0.00	**11.21 ± 0.00**	6.83 ± 0.00	8.51 ± 0.00	8.06 ± 0.00	6.34 ± 0.00
Fats (%)	**6.51 ± 3.33**	3.50 ± 1.19	3.11 ± 1.67	3.43 ± 1.97	4.10 ± 1.88	3.33 ± 0.92
Minerals (%)	3.18 ± 2.36	2.91 ± 1.56	3.25 ± 2.04	2.03 ± 0.11	**8.48 ± 3.13**	2.53 ± 1.40
Moisture (%)	3.19 ± 0.71	2.56 ± 0.39	4.01 ± 0.32	**4.15 ± 0.29**	3.10 ± 0.67	2.79 ± 0.20

4.0 CONCLUSION

The incorporation of *M. koenigii* and *G. gnemon* into herbal cookies highlights a wide spectrum of nutritional compositions, with each formulation offering distinct advantages. This emphasises the flexibility to accommodate diverse dietary preferences and nutritional needs. The study's findings emphasise the potential for customised nutritional offerings by fine-tuning the proportions of these herbal ingredients in cookie formulations. Beyond this adaptability, the integration of functional and nutrient-rich cookies holds promise in meeting the demand for portable, energy-dense provisions, especially relevant for armed forces with specific dietary needs in challenging environments. The study underscores the dual significance of these herbal cookies as customisable nutritional options and as potentially valuable provisions in demanding contexts such as military settings.

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Defence Logistics: An in-depth analysis of 3D Scanning Technologies and how to use them to replace damaged parts

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ABSTRACT

A 3D scanner is a device that scans the surface of an object using light. This scan can then be used to recreate the object. In this paper we aim to inform the reader of the ways low-cost 3D scanners can be used by anybody to replicate important parts of objects if they get damaged. This paper mainly focuses on the CR-Scan Lizard, though the principles will apply for other scanners. It details the technology behind the scanner, the method to using the CR-Scan Lizard, how to improve scans, and limitations of the scanner. The hope is that this paper will serve to encourage and enable more people to see 3D scanners as a viable fix if things get damaged.

Keywords:

3D scanner, 3D scanning, replication, fabrication, fix broken objects, replace damaged parts.

1.0 INTRODUCTION

A 3D scanner is a device that can digitally construct a 3D model of an object. They come in many sizes, from large ones used by satellites to smaller handheld ones and have long been used in many industries. They are already used for topographical mapping of danger sites allowing for people to remotely read the land and better predict hazards like landslides without risking being physically there for too long [1]. Smaller ones are being introduced in medicine to scan the bones and limbs of patients and for modelling prosthetics [2].

3D scanners are often used to preserve items of heritage, where accuracy is important. In 2004, there was a collaboration between institutions to scan the pyramids in Egypt. Using a variety of scanners, they were able to scan the pyramids in detail. This allowed them to virtually investigate and explore the pyramids without having to physically be in them and cause possible damage. This virtual investigation led to the discovery of anomalies in the structure of the Great Pyramid of Giza that gave insights into its construction [3].

For smaller scans, we can look to the scanning of the terracotta army. The terracotta army is a collection of life size pottery figures that were found buried surrounding the tomb of the first Chinese emperor. Scanning an object allows you to zoom in on the scan on a computer. This allows for the inspection of smaller details that previously may have been missed. In the case of the terracotta army it allowed for more clear viewing of the carvings and engravings on the models, giving us greater understanding and appreciation of the sculptors of that era [4].

The scans of these artifacts can also be used to create identical replicas. Many museums display replicas of invaluable artifacts using scans done from 3D scanners. This allows visitors to handle the replica and fell like they're handling the actual object without there being any risk of damage. An example would be the Frog Clan Helmet replica in the Hudson Museum in the University of Maine. They were asked to return the original helmet so they 3D printed a replica so visitors to the museum can see this piece of heritage without the original owners having to lose it [5].

This shows that 3D scanners can be used to fabricate replicas that are accurate. This allows them to be used in the military in various ways. If bespoke parts are damaged and you urgently need new ones, you can scan the fixed part from a different object and then 3D print the replica then and there. That way you don't have to wait around for parts to come in. As technology advances, 3D scanners become cheaper and less resource intensive to use. They're also smaller meaning you can require less set up and people to use them. Different 3D scanners use different technology and thus have different advantages and disadvantages.

The CR-Scan Lizard is what is known as a structured light scanner. This mean, it works by projecting a pattern of light onto the surface of an object. On either side of the projector is a camera. These cameras detect the location of points in that pattern of light and compare them to what the pattern is supposed to look like. The difference in the detected location of the points and the location they should be in is caused by the light being obstructed by the object's surface [6]. This data is used to form a point cloud which can be used to generate a mesh of the object's surface from the viewing angle. With sufficient meshes you are able to create an accurate model of the entire object.

There are two main advantages to this approach. The first is simple and it's that a structured light scanner doesn't need to contact the object. This means that the object is completely unchanged after it has been scanned.

The second advantage is its increased speed and reliability. Using a whole pattern of light allows you to detect many points on an object's surface at once. In the case of the CR-Scan Lizard it allows you to detect the entire field of view of the cameras at one time. This means scanning the whole object can be done quickly since so much of it can be scanned and the point cloud created in so little time. Also, detecting so many points at once means if the object or your hand is unstable, there's less likely to be errors when creating the model. This is because there are so many other accurate points in the point clouds that the algorithm can know to ignore your errors.

These advantages are particularly useful for the scanning and replicating of vital parts that one wouldn't want to risk damaging.

2.0 METHODOLOGY

This is a detailed guide on how to use the CR-Scan Lizard. It's a mostly straight forward process with very few complications likely to arise.

1. The CR-Scan Lizard works with a free computer software called CRStudio, so you first want to download this. Make sure you download the latest version for your device i.e. windows or mac.
2. After you have downloaded and installed CRStudio, there will be options for either handheld or table mode, so this is up to you. It doesn't matter because you can change it later if you want.
3. Connect the scanner to your computer.
4. At the top left click 'File', then 'Import_calib' then 'Network Download' then 'Import'. This imports a calibration file to ensure the scanner works properly

Handheld mode:

1. Select 'Easy Scan'.
2. Place the object you wish to scan on a flat, featureless surface with no other objects nearby.
3. Hold the scanner vertically with the cable pointing downwards
4. Move around until you have a good amount of the object in frame
5. Click 'Scan'
6. Move back and forth along the object to build up the image
7. When you feel you have enough detail from that angle click the button again
8. Click 'Append'
9. Keep doing scans from various angles until you feel you have enough
10. Use the eye icon next to the scans to view only selected ones
11. Select areas you want to remove from the scans by pressing ctrl + left click
12. Press the delete key
13. Click 'Align' and it should automatically align all your scans
14. Click 'Process' and a model of your object will be generated

Table mode:

1. Select 'Easy Scan'
2. Set up your turntable
3. Click on the Preview button
4. Place the object on the turntable and move the scanner and turntable until

you're happy with how much of the object is in frame

5. Click on the same button and remove your object
6. Click 'Initial'
7. Click it again after a few seconds. These 2 steps let the scanner scan just the turntable so it knows to automatically remove it when generating your model
8. Put your object back on the turntable and press 'Scan'
9. After it completes the scan (around 30sec) you can press 'Append' then change the orientation of your object and scan it again.
10. Once you feel you have enough scans click 'Align' and it should automatically align all your scans
11. Click 'Process' and a model of your object will be generated

Occasionally you may find that after clicking align your scans aren't aligned correctly. To overcome this, you can manually align any scans that didn't align correctly.

First, click the eye icon next to the scans so that only one correctly aligned scan and one incorrectly aligned scan are visible. Next click 'Align' at the top right then click 'Manual'. Your two scans will now be shown separately. On the right you can click to select point 1, 2 or 3 and the right click on matching parts of your two scans to align them e.g. select point 1 then right click on the top spire of the mosque in both scans. After you have done this with as many scans as is necessary you can press 'Process' to generate the model.

Another problem can be you can't import the calibration file. If this occurs, make sure your scanner is connected to your computer and switched on, then restart CR Studio and try again.

Figure 1: The CR Scan Lizard with the handle we printed for it.

Looking at **Figure 1**, you can see that the scanner isn't very ergonomic. It has a smooth, featureless surface with rounded edges. Holding it to use it for an extended period of time can cause wrist and finger pain. The solution is to print and use an ergonomic holder with handle for the scanner. This holder has been designed specifically for the CR-Scan Lizard so it's likely to be better than a generic handle you buy off the market. The scanner has a screw at the bottom for a tripod, but the scanner is heavy and it is best to not try to hold it from just that one point as we had a tripod break doing that.

To ensure the most accurate scans it is important to attempt to, as close as possible, meet as many of the following criteria as possible.

Firstly, you want to ensure that the object you're scanning isn't too dark, too light or too transparent. As mentioned, the scanner works by projecting light and detecting distortions. You want colours that aren't going to absorb or reflect too much of the light.

Next, you want to ensure there aren't many shadows. This can be done by trying to ensure you orient the object correctly, or by shining a light the correct way, for example, a ring light to cancel out shadows.

Finally, try to ensure you're scanning in an environment with consistent lighting. If the lighting changes on different parts of the object or while you're scanning it can mess with cameras analysis of the pattern distortion.

3.0 RESULTS

Referring to **Figure 2.1**, on the left is the object we scanned, on the right is a 3D printout of our scan. As you can see, the scanner has the ability to detect lots of details. The small horn at the front of the model and all the bumps on it skin were clearly detected as they can clearly be seen and felt in the print. Where the eye is in the object you can see an attempt at an eye in the printout, although it's less detailed. We suspect that this is due to the precision of the 3D printer we used and not the scanner.

Looking at **Figure 2.2**, on the left is the model and on the right is a printout of our scan of the model. As you can see the scanner couldn't properly detect the tapering tail so the tail ended up being printed too wide. Also, the toes of the dinosaur are a thin lattice pattern so they weren't detected properly by the scanner either.

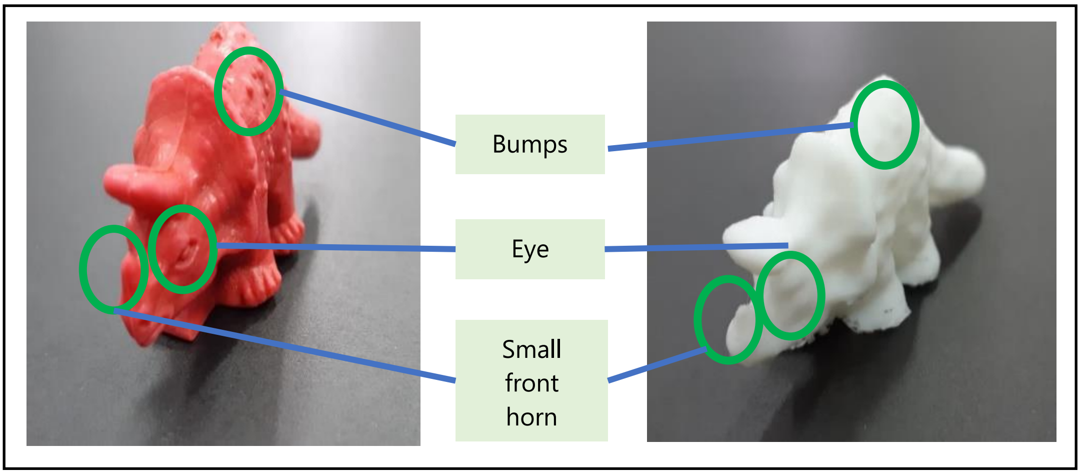

Figure 2.1

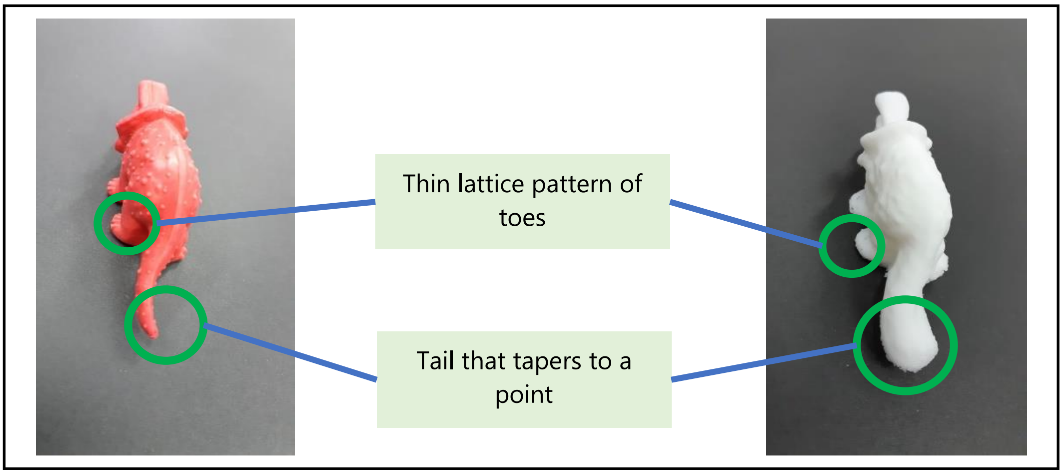

Figure 2.2

4.0 DISCUSSION

The cost of and technology used by the scanner will obviously affect its limitations. In the case of the CR-Scan Lizard, a low cost structured light 3D scanner, it is important to know its limitations so you don't end up with lots of unusable scans.

Since it projects light to make its scans, objects that greatly affect the distortion of the projected light tend to result in less than ideal scans. Objects that are too dark or too light either absorb or reflect too much light thus interfering with the cameras' readings and resulting in inaccurate scans. Often times you'll find that your scan is just totally unusable if the object was too dark or too light. Shiny objects also reflect too much light and render the scans unusable.

Transparent objects let too much of the projected light through them. This means they may not distort the pattern enough and can just not register sufficiently on the cameras.

In **Figure 2.2** above you can see other limitations of the scanner. The toes of the dinosaur are a repeating thin lattice pattern. Since they're all identical and right next to each other, the algorithm of the scanner fails to identify them as different features resulting in them being clumped together as one.

The reason we think the thin tapering tail wasn't scanned correctly is because as the tail tapers off, there aren't enough unique details for the scanner to identify. It sees the detail of the bigger part of the tail and tries to correct what it thinks is an error as the tail tapers off.

You also need to be careful with heavily symmetrical objects. If an object has lots of symmetry and not enough unique points are scanned, the automatic alignment may align your scans incorrectly resulting in a less accurate model. This can be easily be fixed though by manually aligning your scans as long as you're able to distinguish the different symmetrical parts of the object.

Dark, light, shiny and transparent objects can all still be scanned though. You need to spray them first with either a spray made specifically for items to be scanned or dry shampoo spray. Both of these will coat the item in a thin off-white layer that isn't too bright. You can then wash off the spray after scanning as long as water won't damage the object. If water will damage the object make sure to buy a spray that will dissolve in air over time. If you don't have any spray there is always the option of covering the item with some opaque tape that easily comes off. In this way you're able to scan these hard to scan items with a cost-efficient scanner.

5.0 CONCLUSION

Although there are limits to what the CR-Scan Lizard can accurately scan, it is still a good choice of a scanner. It can scan items very quickly, there's no need to mark your items, and it's relatively cost. Just make sure the room your scanning in isn't too dark. If your object has too many shadows from one angle, you can just change its orientation to scan it. Because of its relatively low price, it's easy enough to equip many groups with a scanner in case important parts get damaged and they urgently need a replacement.

There are some limitations, but the CR-Scan Lizard can capture most of the physical features of most small to medium sized objects for relatively low cost. Also, there is still the 'texture' mode of the CR-Scan Lizard provided you have a powerful enough PC.

The scanning by the CR-Scan Lizard in this article is currently 'geometric' only. This means that only shapes and physical structures can be detected. The CR-Scan Lizard does have a texture mode where it can detect colours and therefore patterns on objects without them needing to physically protrude. However, at the time of writing, this mode requires too much time and computing power to fit with the theme of using a low-cost 3D scanner. It doesn't make sense to talk about how to use an affordable scanner that everyone can be equipped with and then say the processing of the scans to make a model requires them to also be equipped with super expensive computers.

In the future, when the software improves or you can get more powerful hardware for cheaper, it would be worthwhile to explore the potential for anyone to get consistent good results from texture mode. This would allow models to be scanned in colour, including any drawings or writings they may have that don't have a light deforming structure. Such functionality could increase the usefulness of the CR-Scan Lizard although identifying of the colour of parts you're printing isn't always crucial.

Another thing that could be investigated in a future study would be using mobile phones. Everyone has them and there are easily accessible apps e.g. Polycam, that can be used to scan objects. If research was to be done as to the effectiveness of these apps, it would also be worthwhile to compare how much better the apps can scan when the phone has lidar capabilities as opposed to when it doesn't. Not all phones do, but specific phones e.g. Samsung S10 5G or iPhone 13, come with built in lidar scanners. Some phones without lidar capabilities have better software and AI technology e.g. Samsung S20 Ultra, that could possibly result in better scans. All these different types of phones with different features would need to be looked into.

Future studies may also want to compare between the CR-Scan Lizard and these different mobile phones. Factors like speed, accuracy, what are the different limitations different phones have, ease of use and cost would all need to be considered. If some of the phones with lidar capabilities are much more expensive for only slightly better scans is it worth equipping everyone with the more expensive option or is it better to equip everyone with a cheaper option and have one expensive option per team? All these different questions would need to be looked into to see what way would be best for the equipping and utilization of handheld 3D scanners to replace damaged parts.

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