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Philip S. E. Farrell, Ph.D.
Defence R&D Canada

David W. Tack, M.Sc., CHFP, Edward T. Nakaza, M.Sc., CCPE, Jordan Bray-Miners, M.A.Sc
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Philip S. E. Farrell, Ph.D.
Defence R&D Canada, 1133 Sheppard Avenue West, Toronto, ON, Canada, M3K 2C9

David W. Tack, M.Sc., CHFP, Edward T. Nakaza, M.Sc., CCPE, Jordan Bray-Miners, M.A.Sc
Human*Systems*® Incorporated, 111 Farquhar Street, Guelph, ON, Canada

Task and physical demands analyses together can identify common and extreme postures and postural sequences, duration, frequency, and forces for Griffon Helicopter aircrew tasks and missions. A tasks and associated physical demands model was developed to estimate neck loads caused primarily by Night Vision Goggle usage. This integrated task and physical demands analysis was used to assess various solutions such as counterbalance or lighter helmets.

INTRODUCTION

Mission duration and Night Vision Googles (NVGs) have been identified as key contributors of neck pain (Adam, 2004; Fraser, Crowley, Shender, & Lee, 2015), suggesting that neck structures are impacted adversely by the helmet/NVG system mass properties while aircrew carry out physical tasks during their mission. This neck pain distracts aircrew from performing flying tasks and, in the extreme, may result in aircrew being grounded. Seventy-five percent of pilots and flight engineers (FEs) reported neck pain in the 2014 Royal Canadian Air Force (RCAF) Griffon Helicopter Aircrew Survey (Chafe & Farrell, 2016). Also, in a recent RCAF Surgeon General epidemiology study, the incidence rate and total primary care of common cervical diagnoses was 50.7 per 1000 person-years (Hawes, Whitehead, & Gray, 2014). Clearly, this situation is not sustainable and solutions must be found.

Defence Research and Development Canada Toronto Research Centre has been directed to develop and assess solutions for Griffon Helicopter aircrew under a project entitled, “Neck and Back Trouble Mitigating Solutions.” One of the project activities was to conduct a Mission Function Task Analysis (MFTA) and a Physical Demands Analysis (PDA) for Griffon Helicopter aircrew missions so to understand the extent to which common and extreme postural sequences contribute to neck pain. This project activity produced a comprehensive model of human work called the Integrated MFTA / PDA Model or IMPM (Farrell, Tack, Nakaza, Bray-Miners, & Farrell, 2014). IMPM uses task, duration, and posture information (in the form of motion capture data) to calculate neck load profiles (forces and torques) over a mission. With these profiles, preliminary assessments can be performed where neck loads, caused by current helmet systems and standard operating procedures, are simulated and then compared to the load profiles for new helmet systems and procedural solutions designed to mitigate neck pain.

This paper provides a brief description of the IMPM, derives cumulative load calculations from the IMPM database, discusses solution implications, and summarizes future IMPM studies.

METHOD: IMPM DESCRIPTION

In general, human physical work involves tasks comprising of a sequence of postures. Task Analysis theory suggests that human work can be decomposed and represented as a hierarchy of functions and tasks consisting of many levels of abstraction (DOD, 1999; Miller, 1953). Typically, those levels are described as functional and behavioral tasks and sub-tasks (e.g., “Regular Hover Take-off”, “Scan”, “Land”). Sub-tasks can be further decomposed into postural sequences performed by aircrew: that is, Flying Pilot (FP), Non-flying Pilot (NFP), and FE. For example, “Regular Hover Take-off” sub-task is decomposed as follows (brackets indicate postural sequence execution time as a percentage of the total sub-task time):

FP	- Inside Scan Dash Gauges	(5%)
	- Outside Scan Regular	(95%)
NFP	- Outside Scan Regular	(50%)
	- Inside Scan Dash Gauges	(50%)
FE	- Scan Regular Take-off	(100%)

A PDA may be performed, generating load intensity, duration, and frequency for each postural sequence.

Twenty-one unique functions, 95 unique behavioral tasks and 69 unique sub-tasks, were captured for Griffon Helicopter missions through structured interviews with Griffon aircrew (Tack, Bray-Miners, Nakaza, Osborne, & Mangan, 2014). Forty-eight unique postural sequences were identified: 12, 12, and 24 sequences for FP, NFP, and FE positions, respectively.

Aircrew performed each postural sequence in and around a stationary helicopter while wearing a motion capture system. Motion capture data were collected from 7 pilots, who played both FP and NFP roles, and 6 FEs (Figure 1). Aircrew repeated each postural sequence twice and the best quality trial was chosen. They also repeated each postural sequence with and without NVGs, simulating day and night flying. Thus, mean and peak neck Range Of Motion (ROM) data were collected at the C7 neck joint from the two runs, for each postural sequence, with and without NVGs, and for FP, NFP, and FE positions. For example, Tables 1 and 2 list ROM data for "Outside Scan Regular" postural sequence, without and with NVGs, respectively, and for pilot 4 playing the FP role (FP4).

Figure 1: "Outside Scan Regular" postural sequence shows FP with NVGs at 3 time intervals. Orange device mounted on helmet is one of 17 motion capture sensors.

Table 1: "Outside Scan Regular" without NVGs FP4 ROM

Range of Motion	Peak (degrees)	Mean (degrees)
Right Lateral Bend	14.9	5.7
Left Lateral Bend	-12.2	-6.1
Left Axial Rotation	25.5	18.9
Right Axial Rotation	-45.7	-19.0
Extension	NA (no extension)	NA
Flexion	-30.4	-21.3

Table 2: "Outside Scan Regular" with NVGs FP4 ROM

Range of Motion	Peak (degrees)	Mean (degrees)
Right Lateral Bend	11.8	5.6
Left Lateral Bend	-9.7	-5.0
Left Axial Rotation	34.6	18.3
Right Axial Rotation	-35.9	-17.2
Extension	2.7	1.7
Flexion	-27.4	-17.9

Comparing Table 2 (with NVGs) to Table 1 (without NVGs) as the baseline condition, the largest ROM difference occurs in the flexion direction where FP4 moves a mean of 3.4 degrees less when wearing NVGs. Pilots have indicated that they try to maintain the head in a neutral position when wearing NVGs since additional effort is needed to maintain a stable position when not in the neutral head position.

Also, 'NA' is recorded in Table 1 under Extension. That is, FP4 never extended their neck during the "Outside Scan Regular" postural sequence runs. In contrast, FP4 extended their neck 1.7 degrees on average with NVGs (Table 2). Pilots likely looked under the NVGs causing them to extend their neck backwards.

Table 3: "Outside Scan Regular" w/o NVGs FP4 neck loads

Neck Load Measure	Peak	Mean	Area
Compression (N)	59.6	59.2	1631.4
Tension (N)	NA	NA	NA
Anterior Shear (N)	9.0	4.1	72.2
Posterior Shear (N)	-18.0	-2.1	-27.7
Right Lateral Shear (N)	6.2	2.5	38.6
Left Lateral Shear (N)	-5.9	-1.6	-18.7
Resultant Torque (Nm)	3.6	3.5	54.8
Right Lateral Moment [+Mx] (Nm)	2.2	1.0	13.5
Left Lateral Moment [-Mx] (Nm)	-2.9	-0.9	-13.3
Right Axial Moment [+My] (Nm)	0.4	0.1	1.0
Left Axial Moment [-My] (Nm)	-0.5	-0.1	-2.5
Extension Moment [+Mz] (Nm)	5.4	3.2	87.0
Flexion Moment [-Mz] (Nm)	0.0	0.0	0.0

Table 4: "Outside Scan Regular" with NVGs FP4 neck loads

Neck Load Measure	Peak	Mean	Area
Compression (N)	75.6	75.4	1374.6
Tension (N)	NA	NA	NA
Anterior Shear (N)	7.4	3.8	62.6
Posterior Shear (N)	-2.7	-0.6	-1.4
Right Lateral Shear (N)	8.2	4.0	68.5
Left Lateral Shear (N)	-1.1	-0.6	-1.5
Resultant Torque (Nm)	3.2	3.7	38.7
Right Lateral Moment [+Mx] (Nm)	3.0	1.2	11.4
Left Lateral Moment [-Mx] (Nm)	-2.3	-1.0	-8.9
Right Axial Moment [+My] (Nm)	0.3	0.1	0.4
Left Axial Moment [-My] (Nm)	-0.7	-0.2	-3.1
Extension Moment [+Mz] (Nm)	5.3	3.5	60.1
Flexion Moment [-Mz] (Nm)	-1.5	-0.8	-2.6

The neck loads at C7 are shown in Tables 3 and 4, where the values were calculated by inputting joint angle data into a rudimentary skeleton model that included mass and inertial properties of the HGU 56/P Helmet and NVG.

Several important discrepancies are noted when Table 4 is compared to Table 3. For instance, the mean extension and flexion moments are greater by 0.3 Nm and 0.7 Nm, respectively, when wearing NVGs (Table 4). It seems that pilots provide additional torque to maintain a neutral position and counteract the NVG moment, thus adding to overall neck loading putting soft tissues (muscle, ligaments) at risk for neck trouble (discomfort, injury, pain) (Karakolis, Farrell, & Fusina, 2015). Also, the mean compression force is 16.2 N greater when wearing NVGs, which puts hard tissues (bone and disk structures) at risk.

The IMPM database contains 624 datasheets; one for each combination of postural sequence, NVG condition, and aircrew position. Each datasheet contains over 50 pieces of data including a full length video for each motion capture run. Thus the entire database contains 33000 pieces of information that can be used to conduct many more analyses. Furthermore, cumulative loads can be derived when these PDA data are combined with MFTA operational sequence diagrams. The results of these analyses are provided in the next section.

RESULTS: CUMULATIVE NECK LOADS

Based on the neck pain survey results and correlation with NVG usage and mission duration, it is postulated that the risk of neck trouble increases due to additional neck loads that NVGs afford as well as the cumulative neck loading over the entire mission. It is also postulated that any solution that reduces cumulative neck loads should also reduce the risk of neck trouble. The IMPM was therefore used to calculate cumulative neck loads and in turn compare various helmet systems, missions, and aircrew positions.

Recall that Griffon aircrew functions, tasks, sub-tasks, postural sequences, and neck load estimates were decomposed into individual “building blocks” using structured interviews, motion capture, and a rudimentary neck model. These IMPM elements can be reconstituted for a mission profile thus allowing cumulative neck loads to be calculated with and without NVGs across an entire mission and for each aircrew member.

Two mission vignettes were created to investigate this hypothesis: Logistics Support and Surveillance Mission (Vignette 1) and Slung Load Training Mission (Vignette 2). For Vignette 1, aircrew begin with pre-flight checks, load and transport troops to a forward operating base, transit to an ‘overwatch’ location to perform surveillance, transit to a forward area re-fueling/re-arming point to re-fuel, pick up a slung load and return to base, and then perform post-mission tasks. This mission contained 33 functions and 93 tasks for a total of 5.5 hours without NVGs (day flight), and 5.9 hours with NVGs (night flight).

The Training Mission included pre-flight tasks, three cycles of a slung load task sequence (land, pick-up a slung load, take off, transit a short distance, land, drop off the load, take off, and repeat twice), a return to base, and then post-flight tasks. This mission contained 33 functions and 93 tasks for a total of 2.5 hours without NVGs (Day), and 2.9 hours with NVGs (Night).

A Mission Builder tool was used to reconstruct the mission profiles by placing functions, tasks, sub-tasks, and postural sequences (where mean neck load data are used similar to Tables 3 and 4) for FP, NFP, and FE in chronological order. Thus, the cumulative result for a neck load measure (N or Nm) was calculated by multiplying the mean value by the postural sequence duration (in seconds, s) and then summed over the number of times the postural sequence was performed during the entire mission, and for each position. Tables 5 and 6 summarize the cumulative neck load measures for Vignettes 1 and 2, respectively, and for the FP position only: see (Tack et al., 2014) for all cumulative load analyses and results. Note that the results were normalized by mission total hours (hr) so to compare across vignettes.

Table 5: Vignette 1 Cumulative Neck Loads for FP

Neck Load Measures	Day	Night
Compression (kNs/hr)	212.6	270.3
Tension (kNs/hr)	-0.5	-0.7
Anterior Shear (kNs/hr)	17.2	16.1
Posterior Shear (kNs/hr)	-9.6	-8.9
Right Lateral Shear (kNs/hr)	11.8	19.1
Left Lateral Shear (kNs/hr)	-7.2	-6.5
Resultant Torque (kNms/hr)	13.3	14.7

Table 6: Vignette 2 Cumulative Neck Loads for FP

Neck Load Measures	Day	Night
Compression (kNs/hr)	212.4	269.9
Tension (kNs/hr)	-1.1	-1.5
Anterior Shear (kNs/hr)	18.3	17.7
Posterior Shear (kNs/hr)	-11.7	-12.4
Right Lateral Shear (kNs/hr)	12.8	20.7
Left Lateral Shear (kNs/hr)	-8.3	-8.2
Resultant Torque (kNms/hr)	13.5	15.2

For illustrative purposes, 3 of 7 cumulative neck load measures are plotted in Figures 2, 3, and 4. The red line indicates an equivalent cumulative load for an office worker sitting on a chair with no helmet, looking straight ahead for the mission duration. Except for the resultant torque values for the FP, it is clear that all neck load measures and conditions (vignette, day/night, and position) exceed this base line condition.

Figure 2 shows cumulative neck compression was similar between Vignettes 1 and 2 for FP and NFP (0 – 2% difference). Day and night results for FP and NFP differed by 27% and 31%, respectively. Cumulative neck compression for the FE differed between vignettes by 11% (night) and 10% (day), and the differences between day and night were 24% (Vignette 1) and 26% (Vignette 2). Overall, pilots tended to experience more neck compression than FEs.

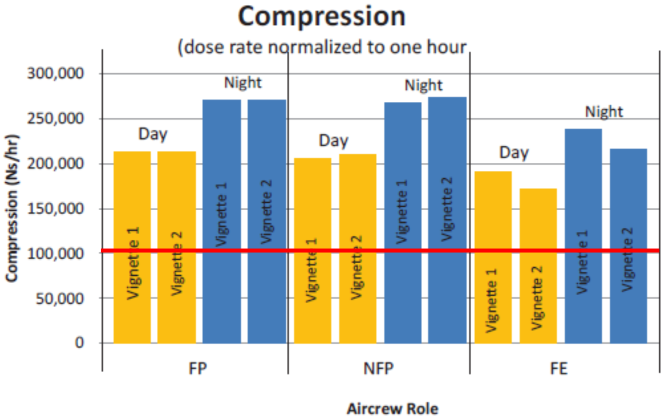

Figure 2: Cumulative Compression Force results Vignettes 1 and 2, day and night flying, and FP, NFP, and FE.

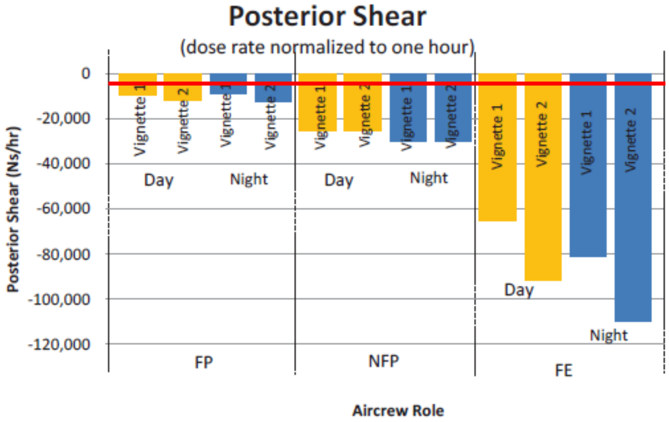

Figure 3: Cumulative Posterior Shear Force results Vignette 1 and 2, day and night flying, and FP, NFP, and FE.

In Figure 3, cumulative neck posterior shear force for the FP differed between Vignettes 1 and 2 by 22% (day) and 40% (night). Day and night results differed by only 8% (Vignette 1) and 6% (Vignette 2). For the NFP, cumulative neck posterior shear force was virtually the same for Vignettes 1 and 2 (0% difference), but day and night results differed by 18% (Vignette 1) and 21% (Vignette 2). For the FE, cumulative neck posterior shear between Vignettes 1 and 2 differed by 40% (day) and 35% (night). Also, day and night results differed by 20% (Vignette 1) and 24% (Vignette 2). Overall, the FE experienced 8.2 and 3.1 times more shear force than the FP and NFP, respectively.

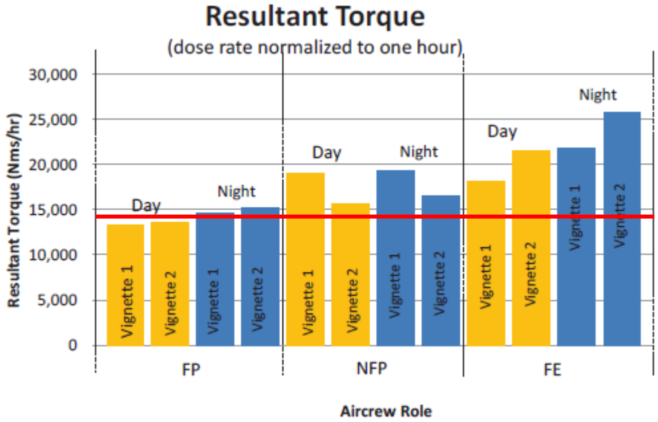

Figure 4: Cumulative Torque results Vignette 1 and 2, day and night flying, and FP, NFP, and FE.

In Figure 4, cumulative neck torque for the FP was similar for Vignettes 1 and 2 (0 – 4% difference). Day and night results differed by 11% (Vignette 1) and 12% (Vignette 2). For the NFP, cumulative neck torque between Vignettes 1 and 2 differed by 22% (day) and 17% (night), and day and night results differed by 1% (Vignette 1) and 5% (Vignette 2). For the FE, the torque between Vignettes 1 and 2 differed by 18% (both day and night). The day and night results differed by 20% (both vignettes 1 and 2). Overall, the FE had 1.5 and 1.3 times more torque than the FP and NFP, respectively.

DISCUSSION: SOLUTION IMPLICATIONS

The IMPM cumulative neck load results clearly show that aircrew experience elevated neck loads, and in some cases more than 20 times greater than office work. The combination of additional NVG mass and postural sequences performed throughout the mission put aircrew at risk for neck trouble. These data may help focus solutions that reduce neck loads due to extreme postures, additional neck borne mass, or aircrew positions.

For example, counter-weight (CW) solutions provide a counter-torque and are regularly employed by aircrew to keep the helmet in a neutral position when wearing NVGs. However, as Figure 5 indicates, CWs are beneficial only in a ‘transit seated’ position and for ‘resultant torque’, and are detrimental with respect to all other postural sequences and neck load measures.

A similar analysis was performed that compares the current helmet to a lighter helmet (Figure 6). The lighter helmet shows improvements in all categories, and such a solution would be worth pursuing. Finally, the IMPM can incorporate new mass and inertia properties, motion capture joint angles, postural sequences, tasks, or task durations that characterise any proposed solution, and similar comparison analyses can be performed. Thus, the IMPM may provide an economical and time-saving preliminary assessment. It does not, however, replace human-in-the-loop assessments because there are a number of assumptions that the model makes (e.g., rudimentary skeleton model in calculating neck loads).

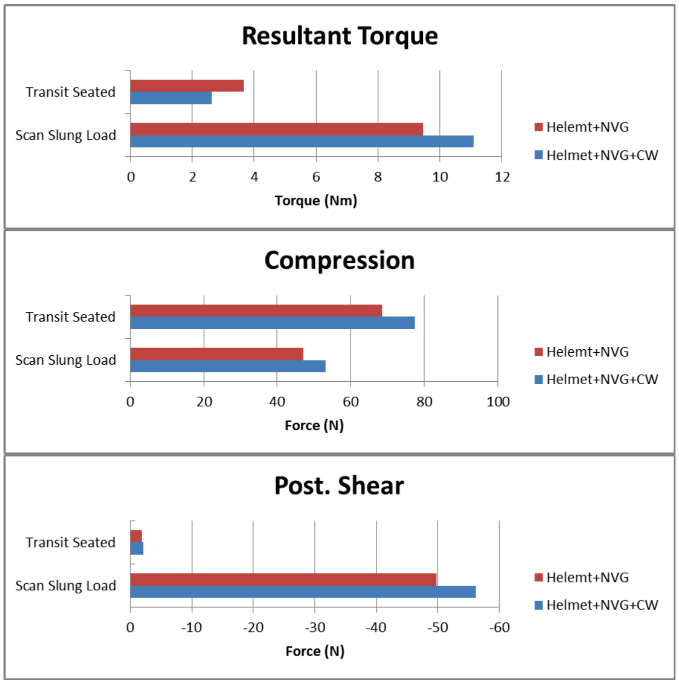

Figure 5: IMPM generated neck load measures for 2 postural sequences, and Helmet and NVGs with and without CW.

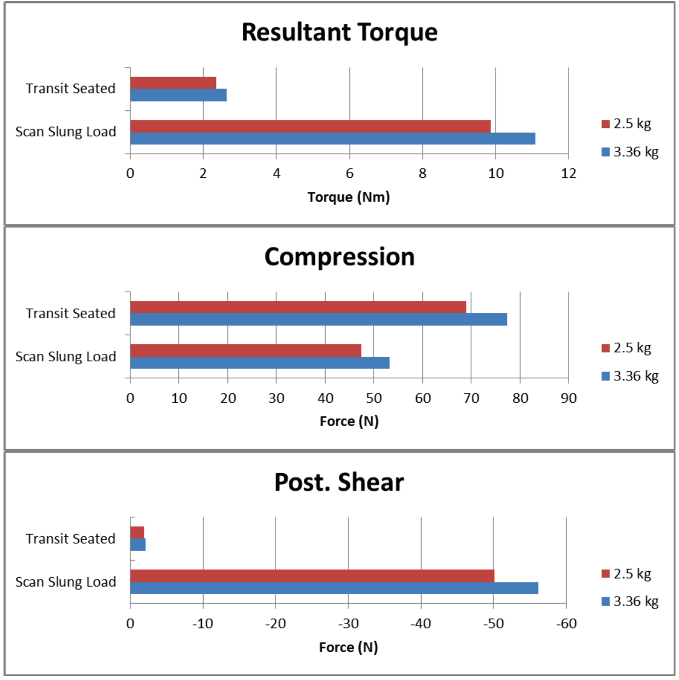

Figure 6: IMPM generated neck load measures for two postural sequences, and two helmet masses.

CONCLUSIONS

IMPM is a modelling and simulation tool that can be used to generate cumulative neck loads for various Griffon Helicopter missions, tasks, postural sequences, helmet configurations, and aircrew positions. Such a powerful tool can be used to guide neck pain mitigating solutions development and assessment. Future studies involve using IMPM to develop and assess new tasks that minimize neck loads, work-rest within a mission, re-distributed tasks amongst FP and NFP, lighter helmet systems and support devices, and improved workstation ergonomics (seats, displays, and controls).

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