A WORKLOAD MONITORING SYSTEM THAT CALCULATES NECK FORCES IN FAST JET PILOTS

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Sport- Load monitoring

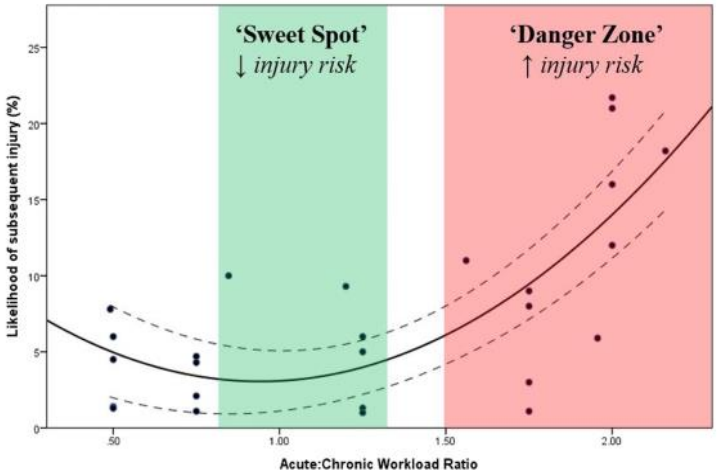
- What is the neck Workload?
- What conditioning loads are best for positive adaptation?
- What loads are associated with neck complaints?

Australian cricket team is using wearable tech to keep bowlers injury free

Innovative 'torpedo technology' also being used by Welsh rugby union team

Most popular st

Guide to interpreting and applying acute:chronic workload ratio data.



Tim J Gabbett Br J Sports Med 2016;50:273-280

BJSM

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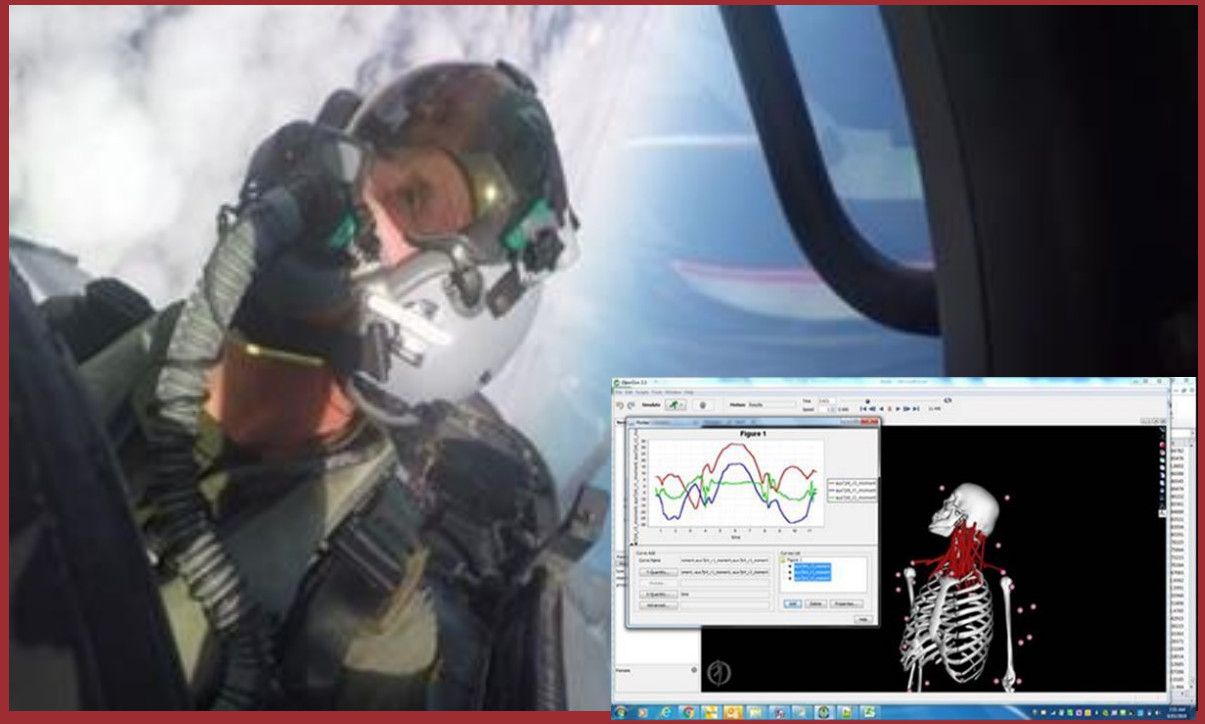
UC Neck Forces Study

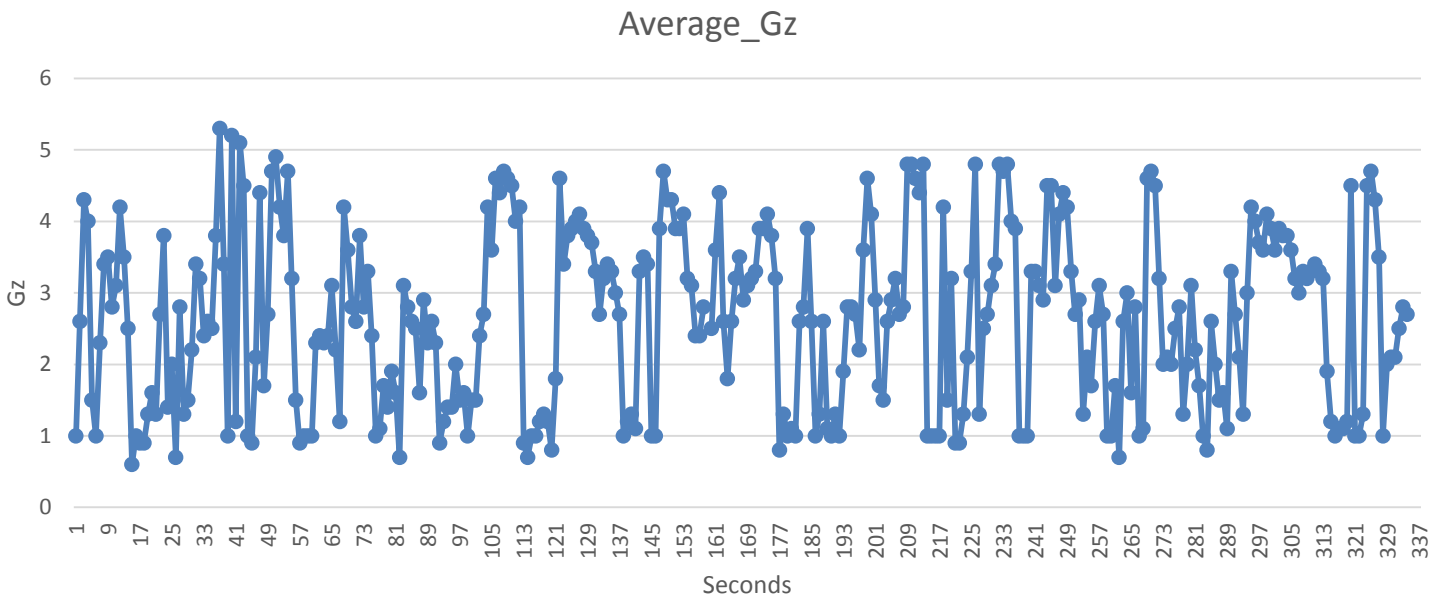


- Peak Loads?
- Cumulative loads?
- Effects of Helmet?
- Effects of Gz?
- Effects of Head Motion?
- Muscle and joint loads?
- Pilot load profiling?
- Future directions

Preliminary Task analysis- video

2 pilots- average 176 head rotations in 10 minutes of flight

Gz profile highly variable… So what is the neck load?

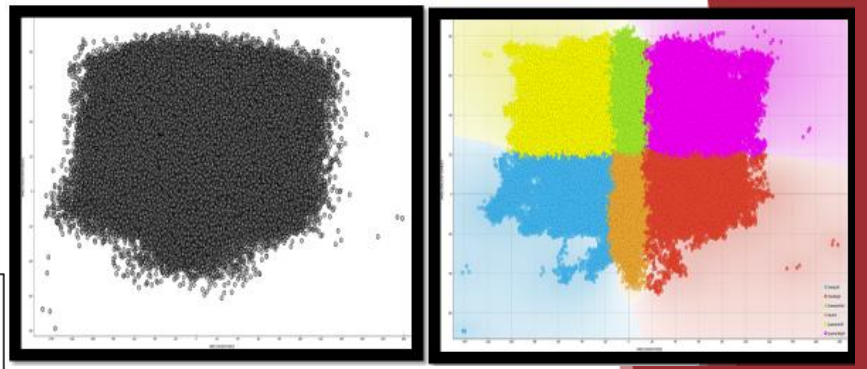


Head Motion Classifier

Confusion matrix for AdaBoost (showing proportion of predicted)

		Predicted						
		CheckLeft	CheckRight	ExtensionHold	Neutral	QuadrantLeft	QuadrantRight	Σ
Actual	CheckLeft	100.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	38329
	CheckRight	0.0 %	100.0 %	0.0 %	0.0 %	0.0 %	0.0 %	41042
	ExtensionHold	0.0 %	0.0 %	100.0 %	0.0 %	0.0 %	0.0 %	28939
	Neutral	0.0 %	0.0 %	0.0 %	100.0 %	0.0 %	0.0 %	89211
	QuadrantLeft	0.0 %	0.0 %	0.0 %	0.0 %	100.0 %	0.0 %	40771
	QuadrantRight	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	100.0 %	39468
	Σ	38329	41042	28939	89211	40771	39468	277760

Head motion counter



Classification accuracy of the machine learners:
LR 2.0%
NB 3.2%
kNN 96.8%
Adaboost 100%.

We have built an algorithm to accurately discriminate, classify, and count 6 head motions

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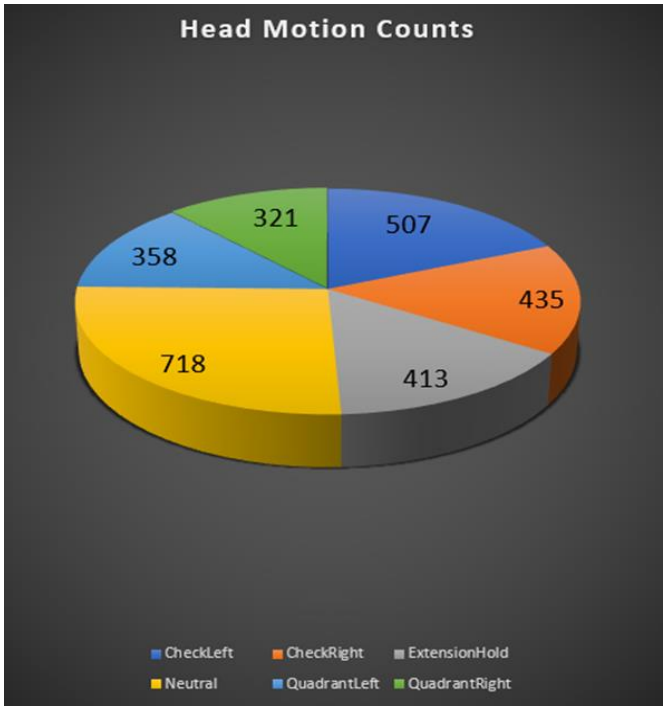
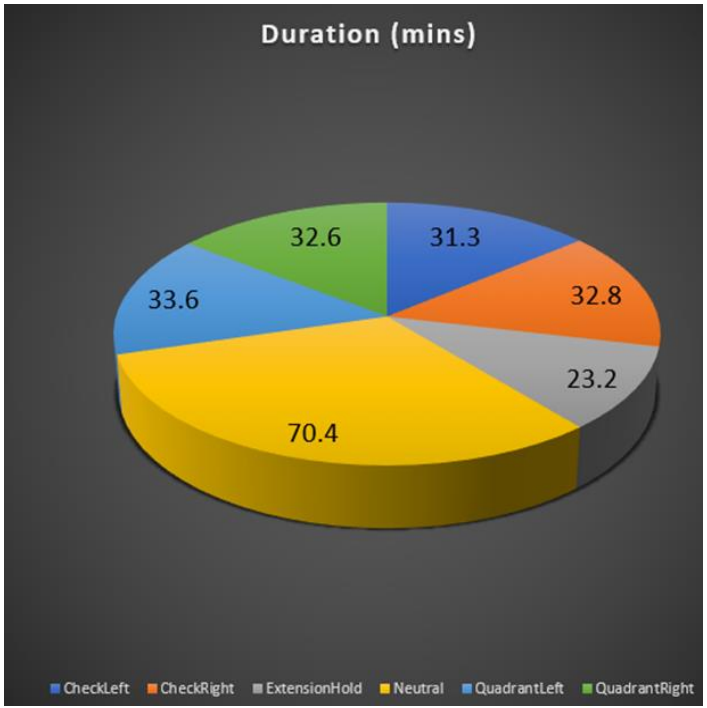
Head Motion Counter

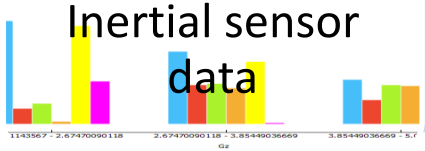
- Reliable head motion counter
- Frequency and Duration and Type





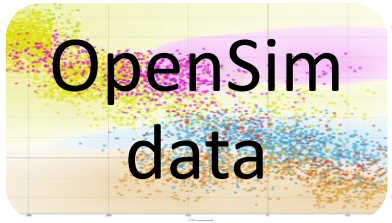
1 sortie-labelled head motions

- Trained and tested MOTION classifier



Inertial sensor data

- Head motion COUNTER



OpenSim data

- Trained and tested FORCE predictor

11 sorties

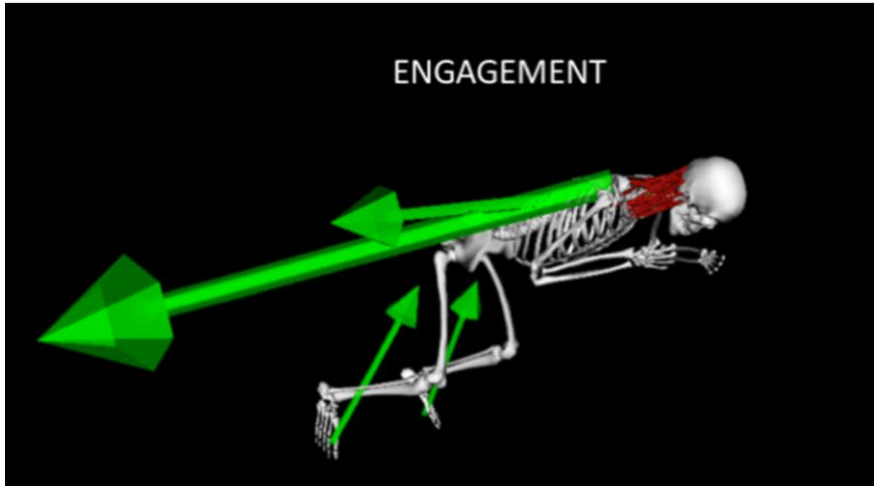
- 42 videos
- Inertial sensor data

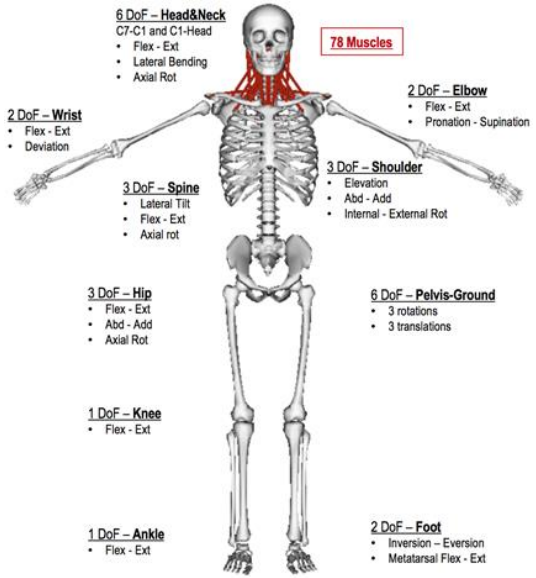
Flight data processor

Workload Report Dashboard

OpenSim modelling

- Using a musculoskeletal modeled developed at Bath University for Rugby Scrummaging, trajectory data was imported into the OpenSim platform



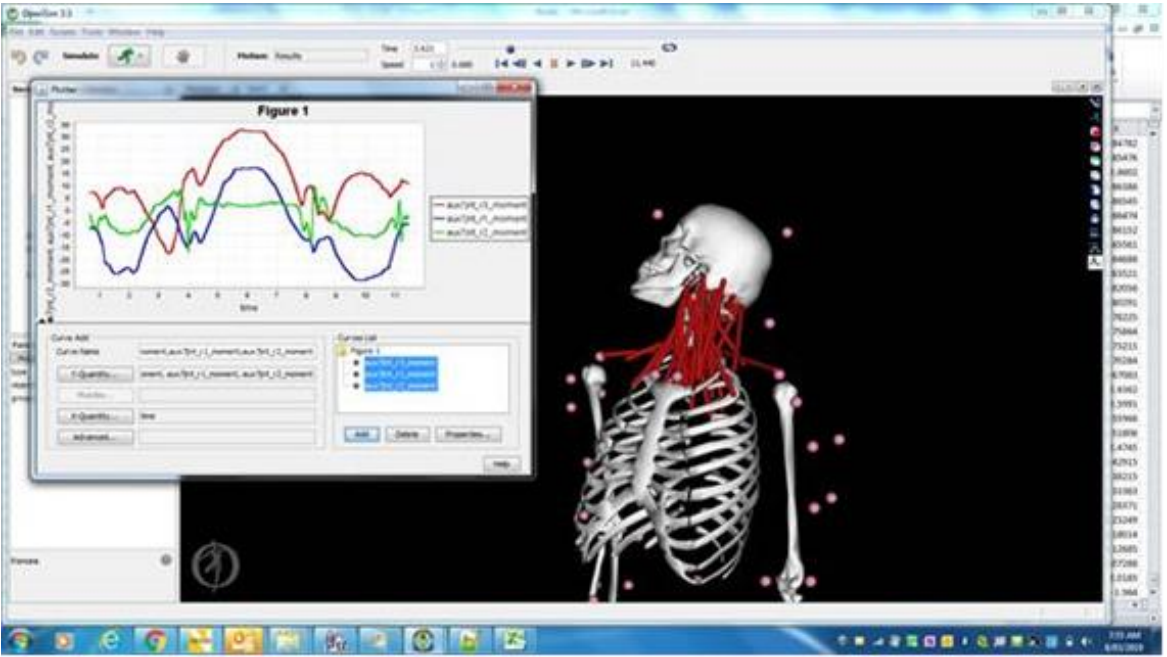


Lab Methods

- 3D trajectory data were collected from 20 retro-reflective markers attached to the helmet, thorax and upper-arms using a motion analysis system
- RAAF pilots performed common aerial combat head checks while sitting in an F/A-18A ejection seat
  - Check Left, Check Right, Extension Hold and Extension Scan
- Two helmets were worn, HGU-55/P and JHMCS

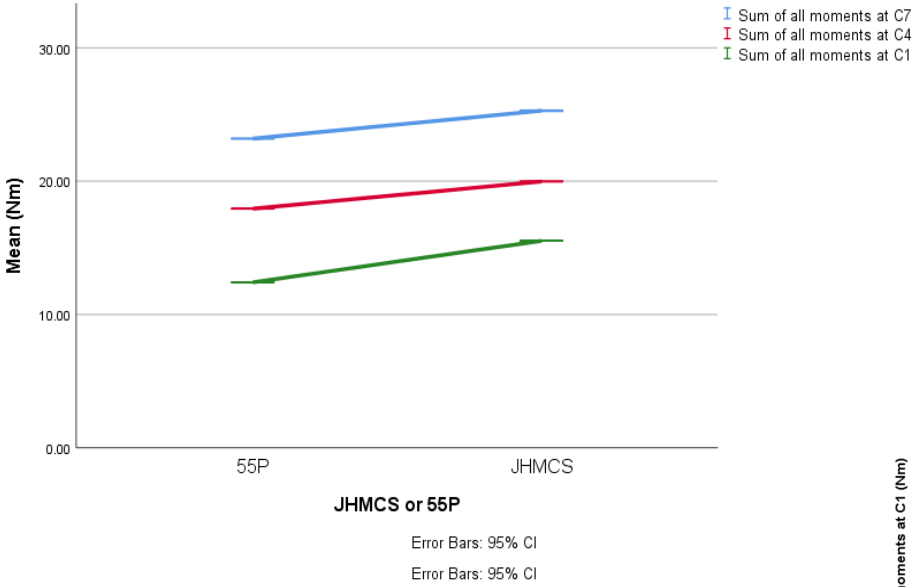
Lab Methods

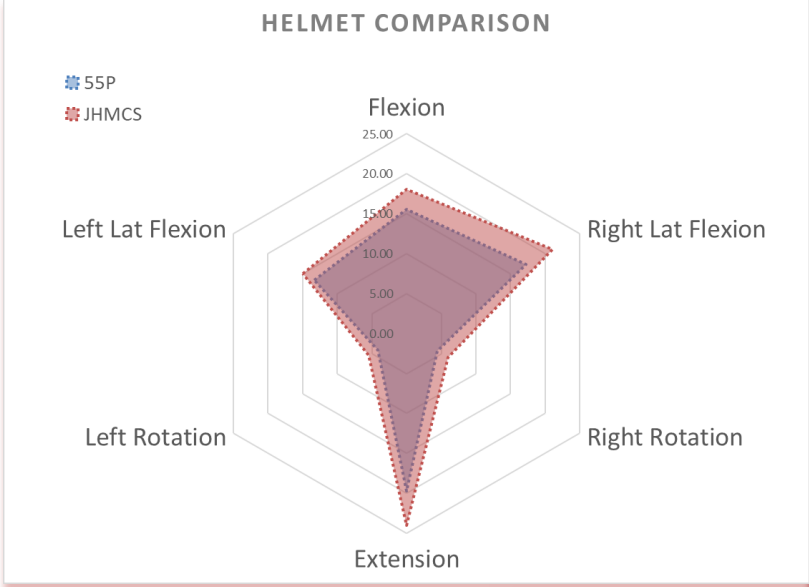
- COM and MOI properties were altered within the model to reflect that of the helmet, before each participants data set was
  - Scaled and inverse kinematics and inverse dynamics created
- The Opensim model has enabled the calculation of neck forces associated with dynamic head motions.



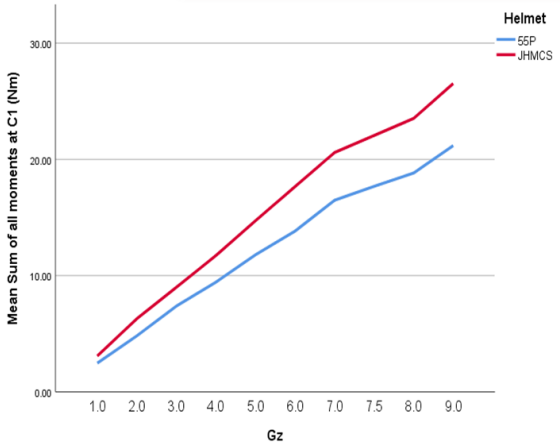
Effects of Helmet

JHMCS is associated with consistently higher neck forces than 55P



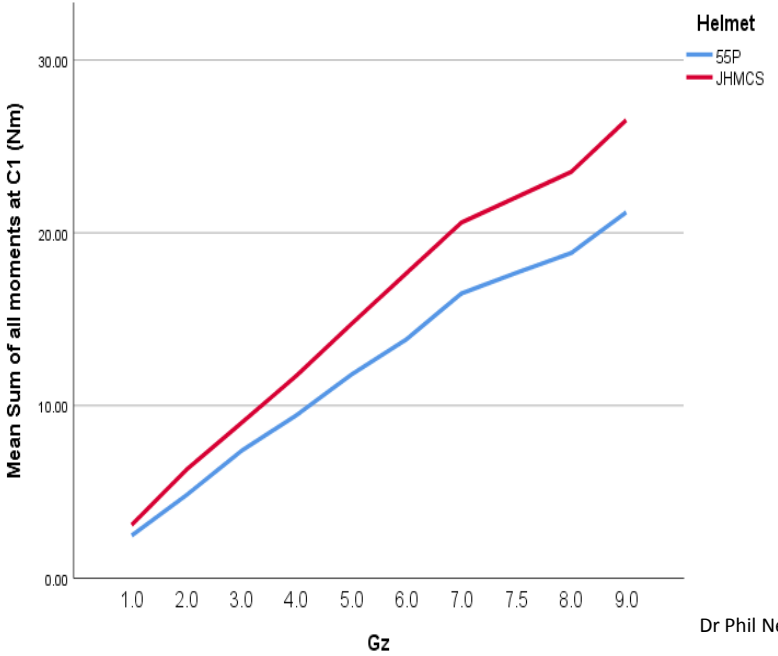


The effect of JHMCS is proportionally greater at C1.



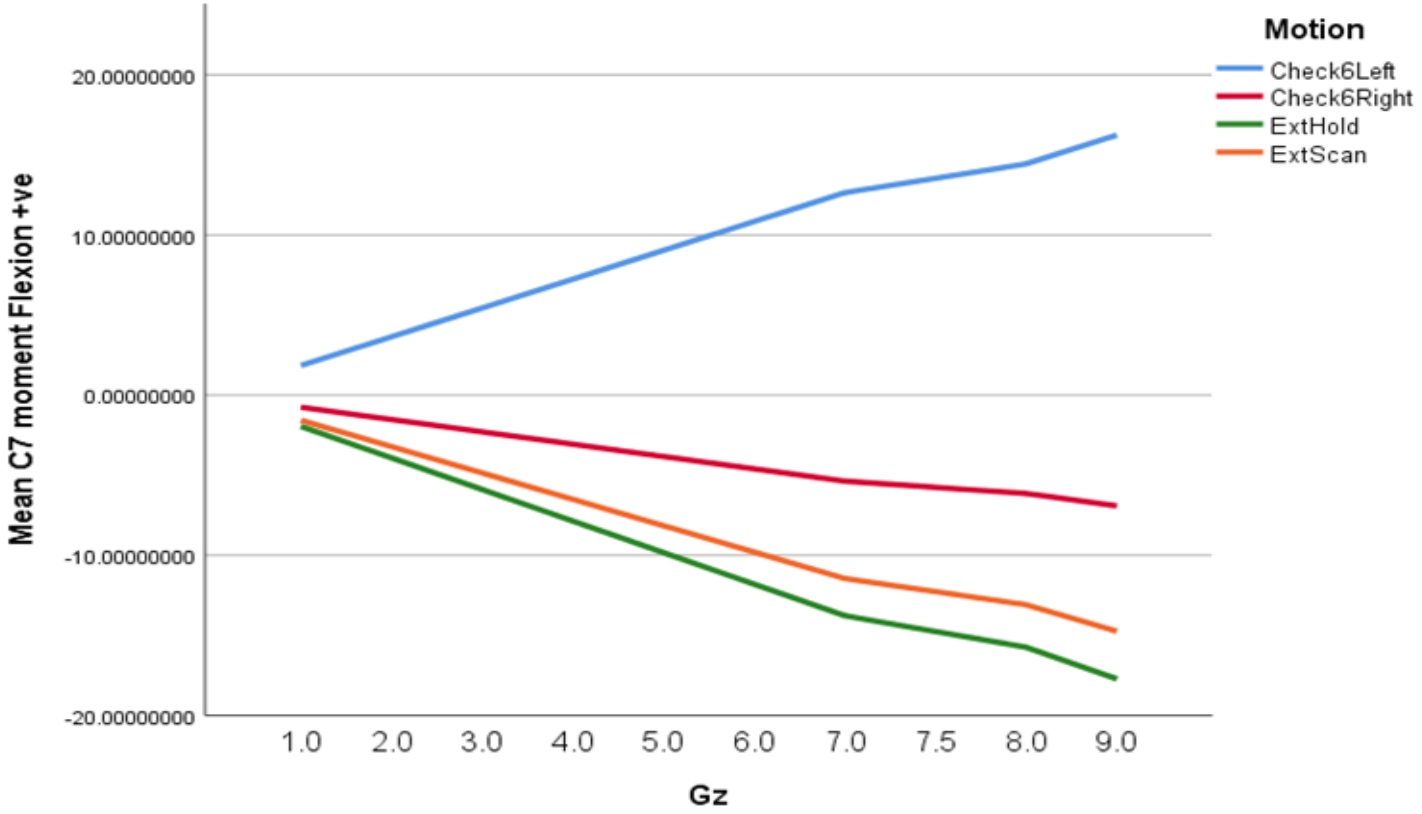
Effects of G force

- Gz increases neck force linearly at all segments.
- Every 1 unit increase in Gz results in a 10 % increase in neck force when wearing the 55P.
- Every 1 unit increase in Gz results in a 11 % increase in neck force when wearing the JHMCS.



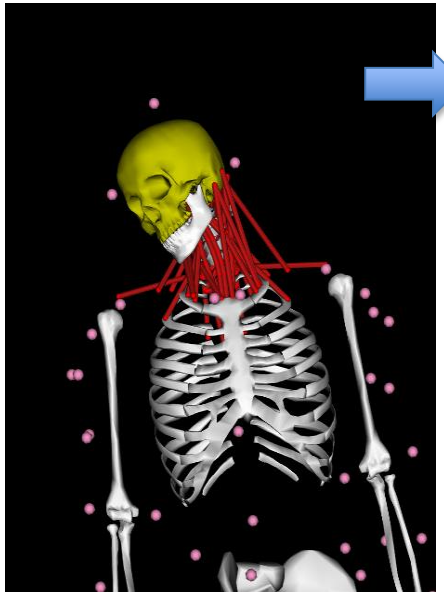
- We now have force predictions for each cervical segment, (and muscle forces also possible)

Effects of Motion Type



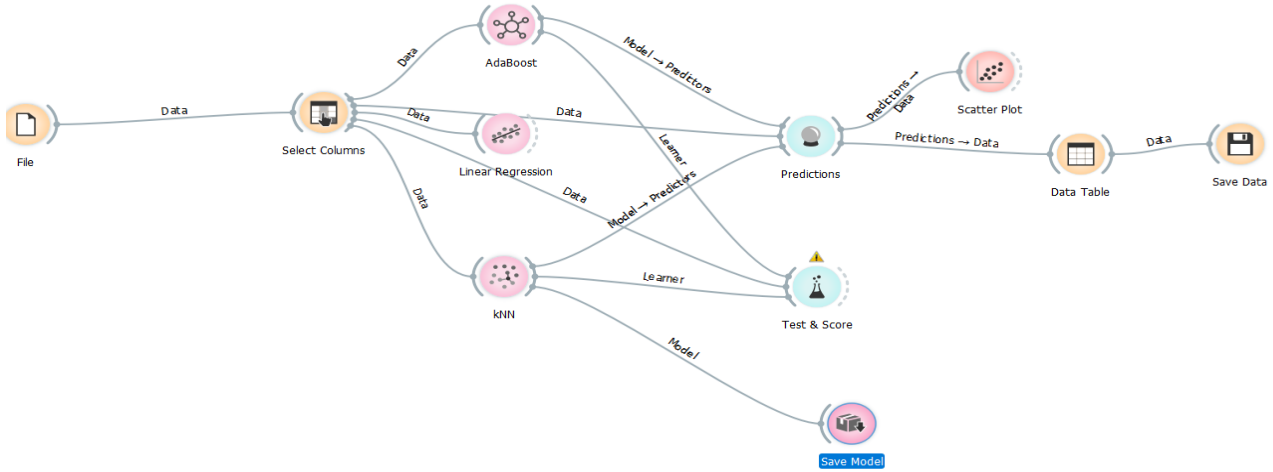
Neck Force Prediction- Lab to Cockpit?

OpenSim model predicts neck forces in pilots



Lab to cockpit

Force predictor machine learners trained on lab data



5 folds of 75% of Opensim data used to train 3 learners
5 folds of 25% of the data set were tested

Features

Filter

- N pitch2
- N roll2
- N yaw2
- N Gz
- C HelmetCondition

Target Variable

- N aux7jnt_r3_moment

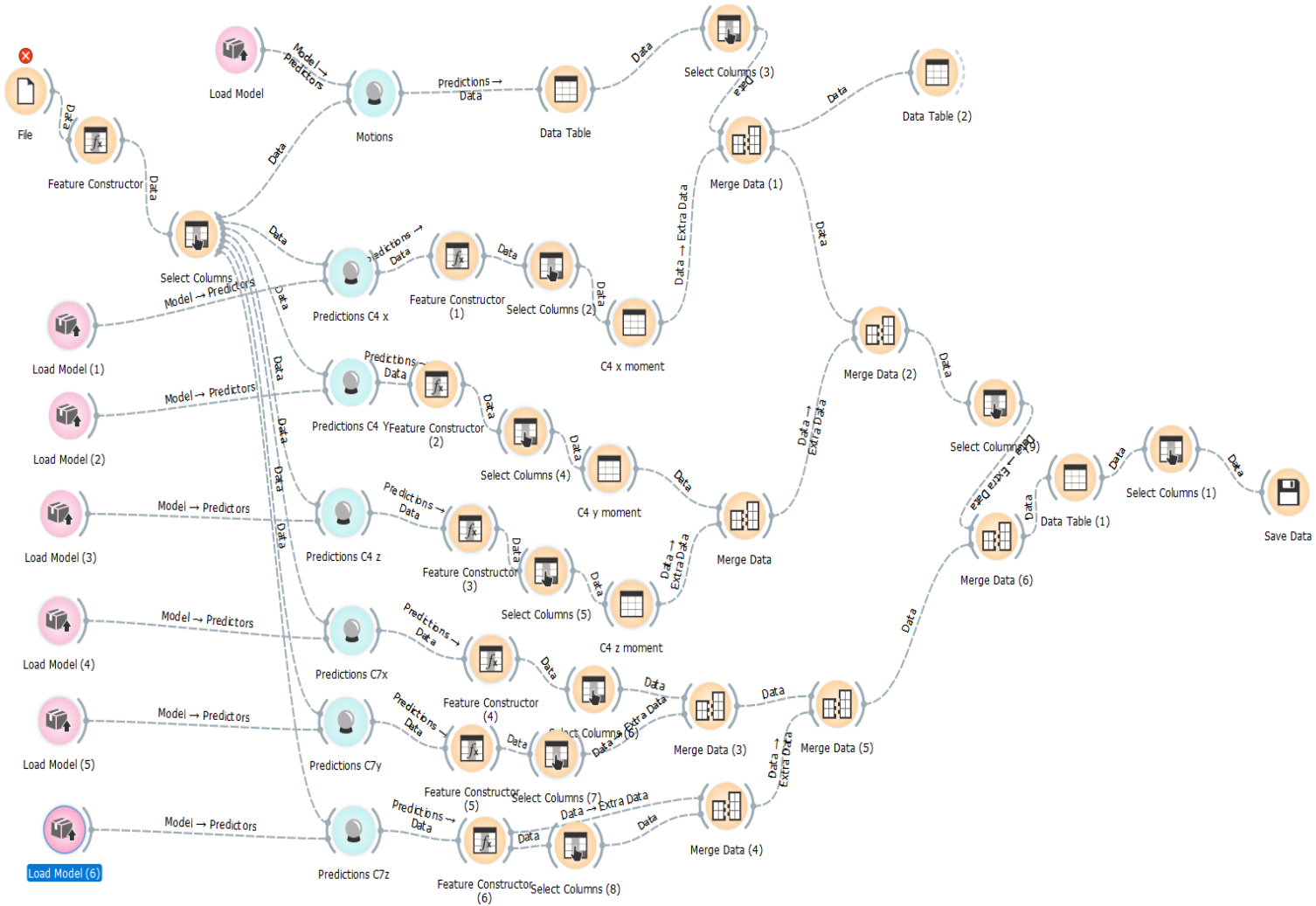
Method - train and test algorithm

kNN	AdaBoost	Linear Regression	aux7jnt_r3_moment	pitch2	roll2	yaw2	Gz	HelmetCondition
-29.71066...	-29.71066...	-14.68522116	-29.71066695	42.76217160	5.61916302	-19.10914842	9.0	55P
-29.65144...	-29.65144...	-14.63400750	-29.65144730	42.90314611	5.54587117	-18.61120241	9.0	55P
-29.81381...	-29.81381...	-14.60319342	-29.81381702	43.10604486	5.26686525	-18.01762868	9.0	55P
-30.16096...	-30.16096...	-14.63981116	-30.16096750	43.21756174	4.91007898	-17.84795077	9.0	55P
-30.85172...	-30.94370...	-14.71875945	-30.85172520	43.40827698	4.18847730	-17.59472409	9.0	55P
-30.94370...	-30.94370...	-14.74584823	-30.94370964	43.44901194	4.02671209	-17.57733500	9.0	55P
-30.99066...	-30.99066...	-14.74081018	-30.99066240	43.44594010	4.01641841	-17.56250758	9.0	55P
-31.08700...	-31.08700...	-14.73975935	-31.08700743	43.47359164	3.92503987	-17.48179660	9.0	55P
-31.50744...	-31.50744...	-14.70303297	-31.50744616	43.47133140	3.66730339	-17.29249402	9.0	55P
-31.61562...	-31.61562...	-14.68957223	-31.61562798	43.47250833	3.54628458	-17.21320117	9.0	55P
-31.93023...	-31.93023...	-14.63214859	-31.93023727	43.44689408	3.24515392	-16.98481373	9.0	55P
-32.01269...	-32.01269...	-14.55088195	-32.01269506	43.42284623	2.98721419	-16.67317472	9.0	55P
-31.97735...	-31.97735...	-14.50147948	-31.97735388	43.41515703	2.91897653	-16.48878304	9.0	55P
-31.69236...	-31.69236...	-14.42070070	-31.69236474	43.48542019	2.79906433	-16.01515067	9.0	55P
-31.44189...	-31.44189...	-14.43123482	-31.44189618	43.59932151	2.81408006	-15.82375563	9.0	55P
-30.16094...	-30.16094...	-15.42815475	-30.16094069	43.98535547	4.01581984	-19.03182173	9.0	55P
-29.24362...	-29.24362...	-15.14711725	-29.24362583	43.94144902	3.96858548	-18.05751659	9.0	55P
-28.95543...	-28.95543...	-15.06393194	-28.95543460	43.94416506	3.95362308	-17.73660997	9.0	55P

Trained machine learners predict neck force based on Gz and head co-ordinates

Excellent fit, error small (0.7-3%)

Method	MSE	RMSE	MAE	R2
AdaBoost	1.275	1.129	0.310	0.994
kNN	4.054	2.013	0.692	0.981
Linear Regression	99.061	9.953	7.677	0.533


File
Feature Constructor
Load Model
Motions
Data Table
Select Columns (3)
Data Table (2)
Merge Data (1)
Select Columns
Predictions C4 x
Feature Constructor (1)
Select Columns (2)
C4 x moment
Load Model (1)
Predictions C4 Y
Feature Constructor (2)
Select Columns (4)
C4 y moment
Load Model (2)
Predictions C4 z
Feature Constructor (3)
Select Columns (5)
C4 z moment
Merge Data
Load Model (3)
Predictions C7x
Feature Constructor (4)
Merge Data (3)
Load Model (4)
Predictions C7y
Feature Constructor (5)
Select Columns (7)
Merge Data (4)
Load Model (5)
Predictions C7z
Feature Constructor (6)
Select Columns (8)
Merge Data (5)
Load Model (6)
Merge Data (2)
Select Columns (9)
Merge Data (6)
Data Table (1)
Select Columns (1)
Save Data
Model → Predictors
Predictions → Data
Data
Data → Extra Data

Lab to cockpit

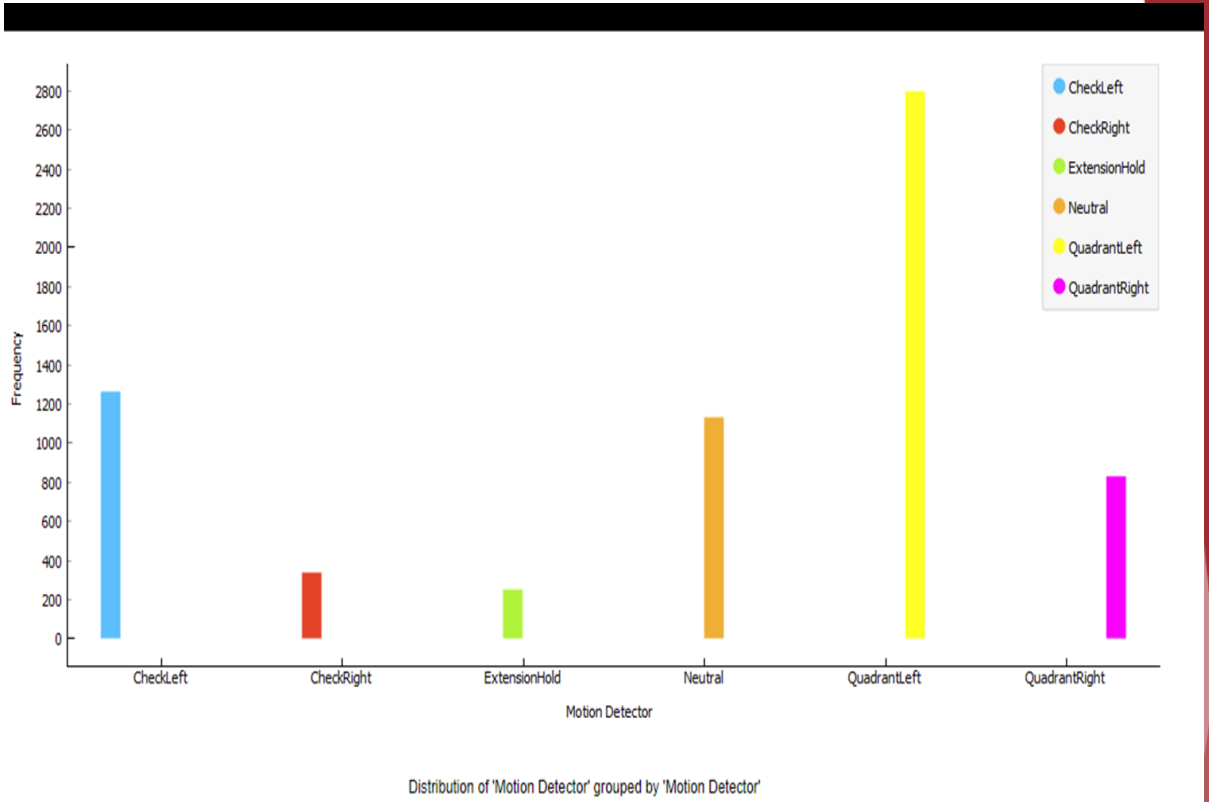
- Video footage of the pilot
- F/A-18A
- Head position co-ordinates relative to the instrument panel
  - JHMCS HMD sync'd with video
  - 7 pilots
  - 11 sorties
  - 42 video segments
- Calculate (predict) neck forces in flight at C7, C4, C1
- Only input is head-mounted inertial sensor data and Gz-meter

Neutral

CheckLeft

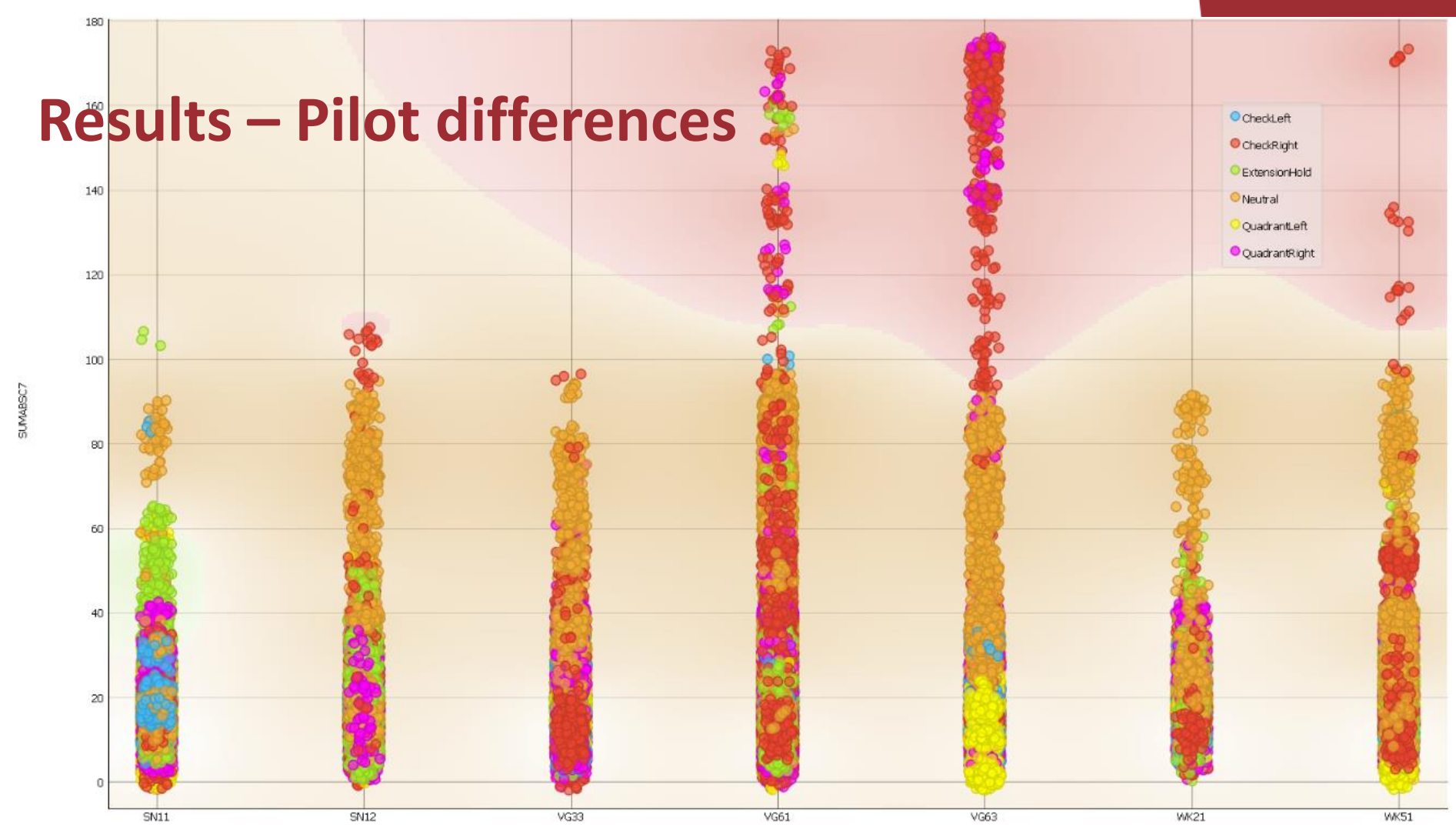
QuadrantLeft (component of High Aspect Pass)

QuadrantRight (component of High Aspect Pass)

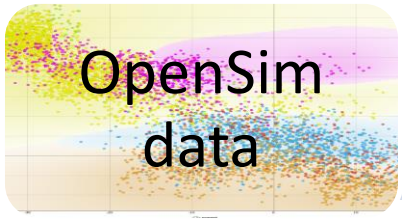


- 6 head motions accurately classified and counted from real flights

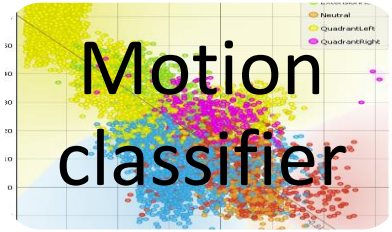
Results – Pilot differences



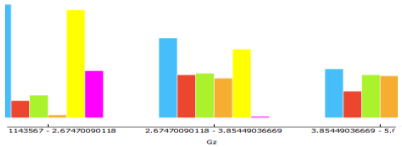
- 42 videos
- Inertial sensor data



- Trained and tested FORCE predictor



- Trained and tested MOTION classifier



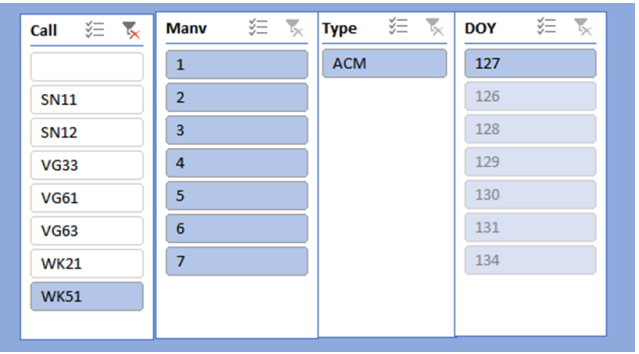
- Head motion COUNTER

NEW ALGORITHM

Workload Report Dashboard

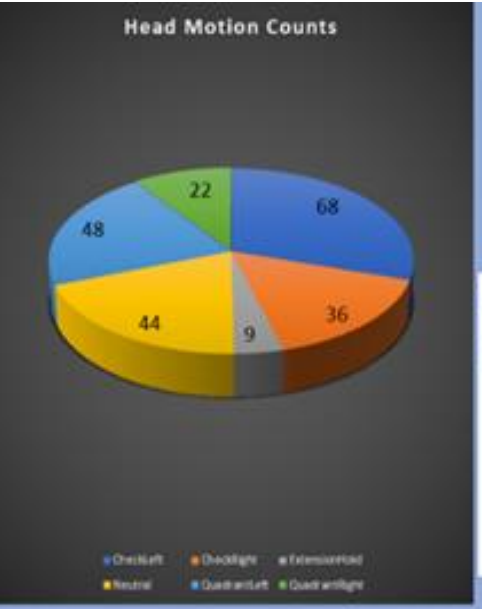
Results- a goldmine

	Peak load C7 (Nm)	Min load C7 (Nm)	Avg load C7 (Nm)	Cumulative Load C7	Duration(sec)	(mins)	Episodes	Avg Gz
CheckLeft	77	0	12	445025	1880	31.3	507	2.5
CheckRight	127	0	14	559925	1966	32.8	435	2.5
ExtensionHold	40	0	17	466381	1390	23.2	413	3.4
Neutral	123	0	10	862259	4222	70.4	718	2.5
QuadrantLeft	52	1	22	900531	2019	33.6	358	3.1
QuadrantRight	91	1	18	690347	1956	32.6	321	3.1

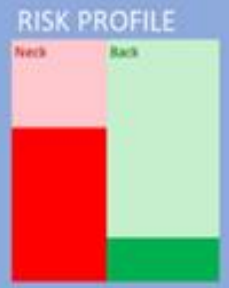


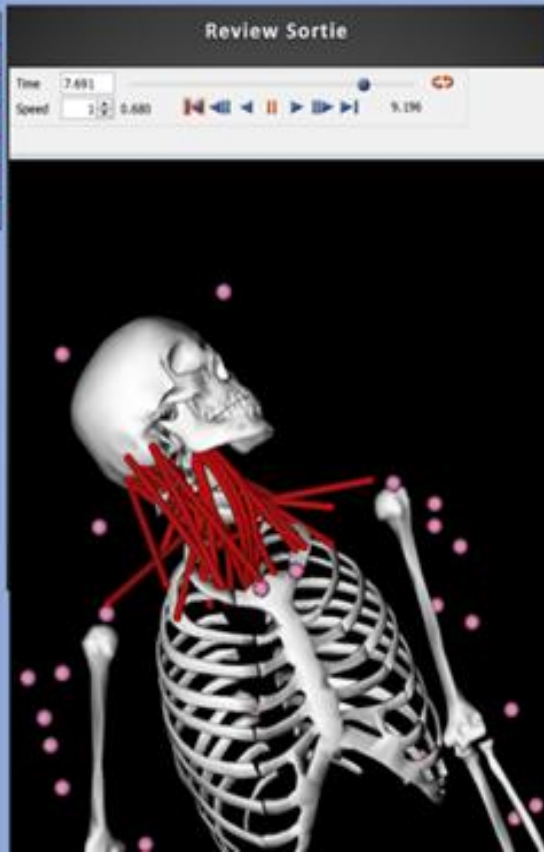
- For example in this pilot;
  - Most time spent in neutral
  - Highest peak load in check right
  - Highest average load and cumulative load was at C7 , in quadrant left position

Results- peak, cumulative, technique, helmet, sortie, segment, muscle…… risk



	Peak load C7 (Nm)	Min load C7 (Nm)	Avg load C7 (Nm)	Cumulative Load C7	Duration (ms)	(mm)	Episodes	Avg Gz
CheckLeft	27	1	11	51277	244	4.1	68	2.9
CheckRight	127	2	15	82430	268	4.5	36	3.2
Extension/Hold	36	3	22	10627	24	0.4	9	2.9
Neutral	83	2	11	65769	300	5.0	44	3.1
QuadrantLeft	36	1	23	158356	338	5.6	48	3.0
QuadrantRight	31	4	16	83231	254	4.2	22	2.9





Summary

This study has shown we can;

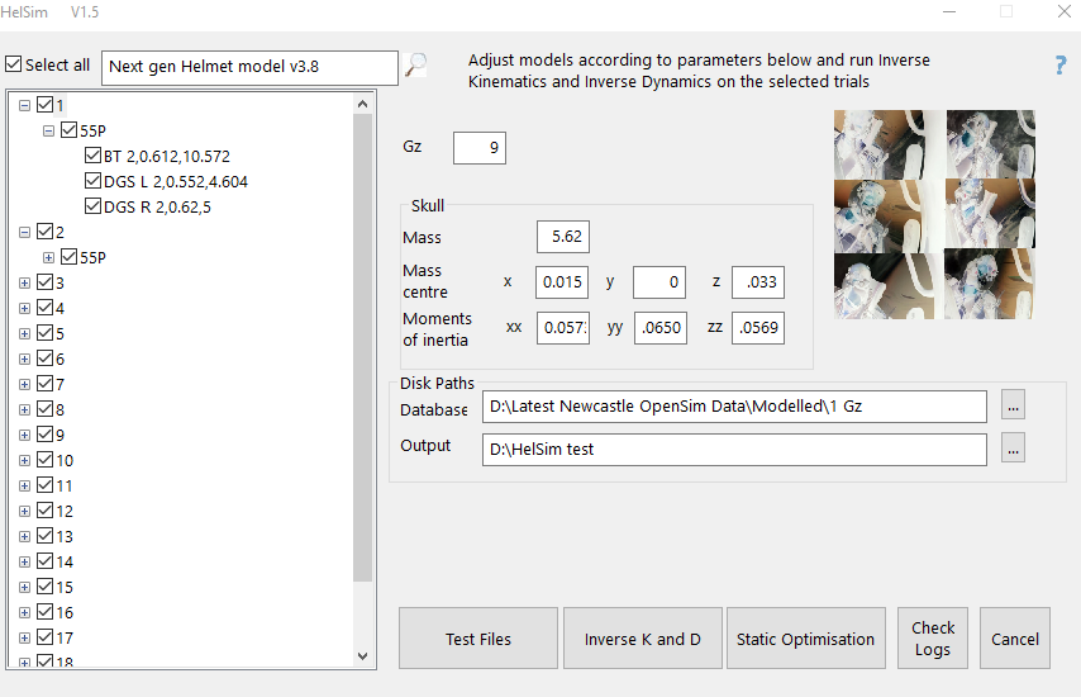
- efficiently and accurately monitor pilot ***workload***
- make ***technical*** review and training more feasible and inform ***conditioning*** loads
- enable access to ***immediate*** post-flight summaries of workload.
- enable prospective ***calculation of risks*** associated with neck forces (further study)
- Conduct comparative modelling of ***new helmet*** designs

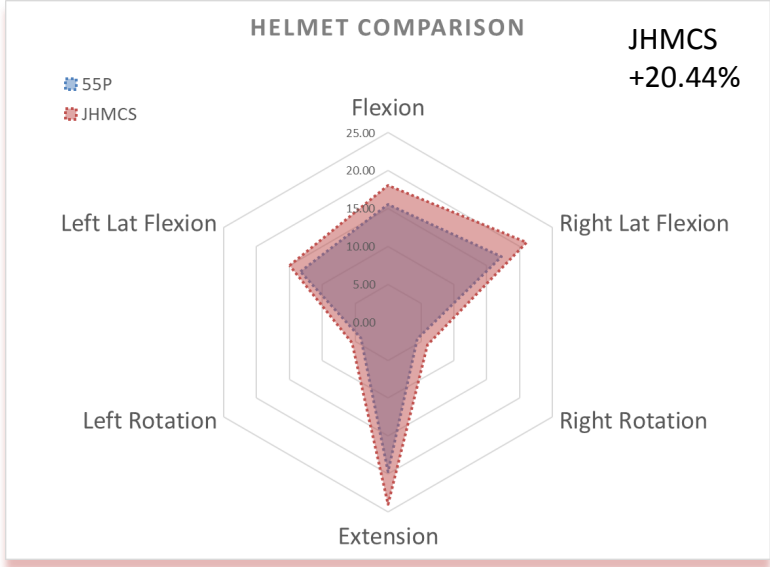
Future

- We are developing Head mounted sensors and interface
- What is neck force and injury relationship?

Future

- We can now quantify the difference between helmets.
- What is best design to reduce neck force?





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Thank you

Air Combat Group – Fighter Fit, WGCDR Carlos Almenara
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Mr James Wallace – Fighter Fit, UCRISE
Ms Amelia Riches- UC Physiotherapy honours
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