Movement Analysis of Firefighters using Gaming and Simulation Technology

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Institute for Work & Health

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Overview

- Background on Firefighter Health and Safety
- FIRE-WELL Research Program
- Microsoft Kinect as a Research Tool
- Current Firefighter Research
  - Movement Analysis Results
  - Simulation Results
- Future Directions

Firefighters in Ontario

- Ontario[1]:
  - 487 fire departments
  - 10 400 full-time firefighters
  - 18 600 volunteer firefighters
  - 200 part-time firefighters

- WSIB Schedule 2 Coverage:
  - Employers are individually liable for benefit costs
  - Incentive for each association to implement health and safety training

1. Ontario Association of Fire Chiefs, 2009

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The Firefighter Demographic is Changing

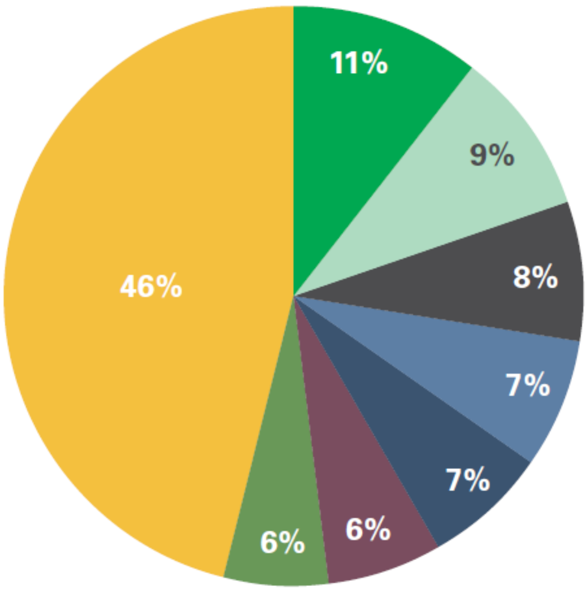
- Growing female representation (approx. 3%[1,2])
- Older workforce[3]
  - Bill 181 – Mandatory retirement age 60

	2007	2008	2009	2010
L-3888 Average Age	45.46	45.9	46	46.28
L-3888 Average Years of Service	17.13	17.41	17.46	17.61
Average Age when starting	28.16	31.69	30.69	30.59
Average age when retiring	55.75	56.06	56.31	56.81
Average years of service when retiring	30.01	30.42	30.54	31.57
Operations				
Captain Average Age	52.61	52.91	53.34	53.85
Captain Average Years of Service	27.66	27.98	28.27	28.58
DC Average Age	58.94	58.15	57.41	57.55
DC Average Years of Service	34.16	33.78	33.66	33.79

1. Service Canada, http://www.servicecanada.gc.ca/eng/qc/job_futures/statistics/6262.shtml
2. Hulett et al., 2008
3. Toronto Firefighter Association, Fire Watch, July 2011.

WSIB Statistics (2012)

2012 Leading Occupations
Schedule 2



- Police officers and firefighters
- Secondary and elementary school teachers & counsellors
- Cleaners
- Childcare and home support workers
- Mail and message distribution occupations
- Other technical occupations in health care (except dental)
- Motor vehicle and transit drivers
- Other

2012 Leading Occupation Characteristics
***Leading characteristics are independent from one another**

Schedule 2	Leading Age Group	Leading Gender	Leading Event	Leading Source	Leading Part of Body	Leading Nature of Injury
Police Officers and Firefighters	35-39	Male	Bodily reaction	Persons (bodily motion or condition)	Leg(s)	Sprains and strains

http://www.wsibstatistics.ca/WSIB-StatisticalReport_S2.pdf

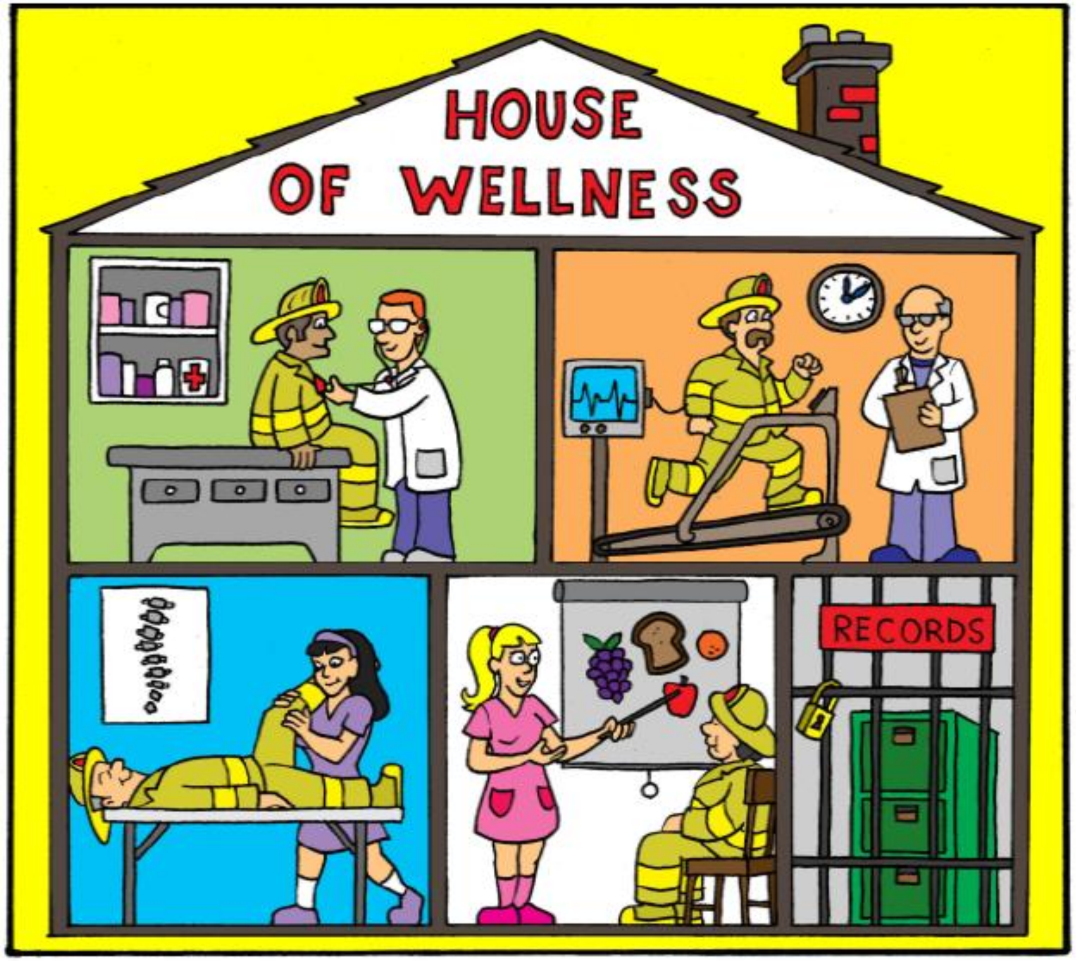
Health and Safety Initiatives

- Need to:
  - Accommodate changing demographics
  - Regularly monitor physical health, fitness levels, and mental health
  - Develop MSK injury prevention training programs and tools

Dr. Steve Miller's House of Wellness
(Ottawa Firefighter's Association)

Medical Evaluation

Injury/medical Rehabilitation



Fitness Evaluation

Behavioural Health

Data Collection

http://www.fitasafirefighter.ca/PDF/wellness.pdf, June 2009.

FIRE-WELL Program

- **F**irefighter **I**njury **R**eduction **E**nterprise: **W**ellness **E**nabled **L**ife & **L**ivelihood (2011)
  - **Participatory initiative** to develop an injury management program with the **Hamilton Firefighter's Association**

- Outcomes:
  - Physical Demands Analysis for Firefighting
  - Annual medical screening test for injury risk identification
    - Critical Incident Survey
    - MSK Screening Form
    - Functional Task Screen

FIRE-WELL Program

- Task Performance Assessment:
  - N = 109 (5 females)
  - Two tasks: hose drag (6.1 kg), stair climb with high-rise pack (19.5 kg) (Candidate Physical Ability Test)
  - Outcomes measures:
    - Performance: task time, grip strength
    - Cardiovascular: heart rate, blood pressure

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FIRE-WELL Program

- Findings and Conclusions:
  - Height, weight, and sex influence task performance[1]
    - Males performed better on: 1) stair-climb task, 2) strength measures
    - Females performed better on: 1) hose drag task, 2) cardiovascular measures
  - Future studies need to investigate movement differences between firefighters.
  - Ergonomic training and feedback is needed to reduce injury risks
    - **TEAM-Feedback** (Technology-Enabled Audit/Analysis of Movement with Feedback)

1. Sinden et al., ACE conference proceedings 2013

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Current Research

- Purpose:
  - To conduct movement assessment of firefighters as they perform three common firefighting tasks
- Partnership:
  - Hamilton Firefighter's Association involved in every step of the study design
    - Rob D'Amico (Captain), Colin Grieve (Firefighter, Union Representative), and Karen Roche (Assistant Deputy Chief)
  - School of Rehabilitation Sciences, McMaster University
    - Dr. Joy MacDermid, Kathryn Sinden, Margaret Lomoton

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Methods

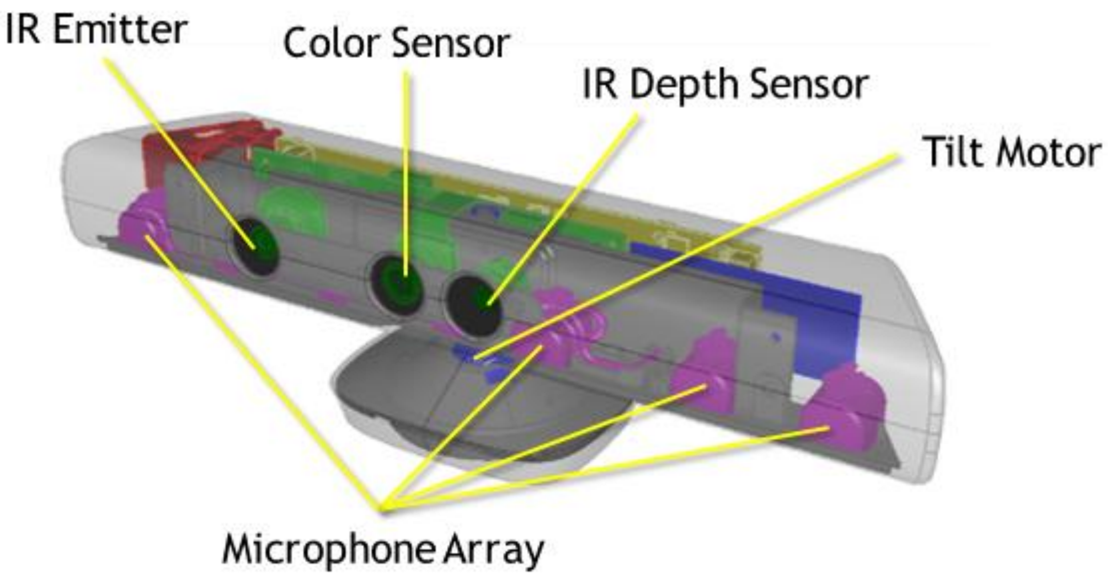
- Tasks: (Candidate Physical Ability Test)
  1) Hose Drag (6.1 kg)
  2) Hose Pull (6.1 kg)
  3) High-rise pack lift and carry (19.5 kg)

- Participants:
  – 48 firefighters (6 female) in full bunker gear plus SCBA (22.7 kg)

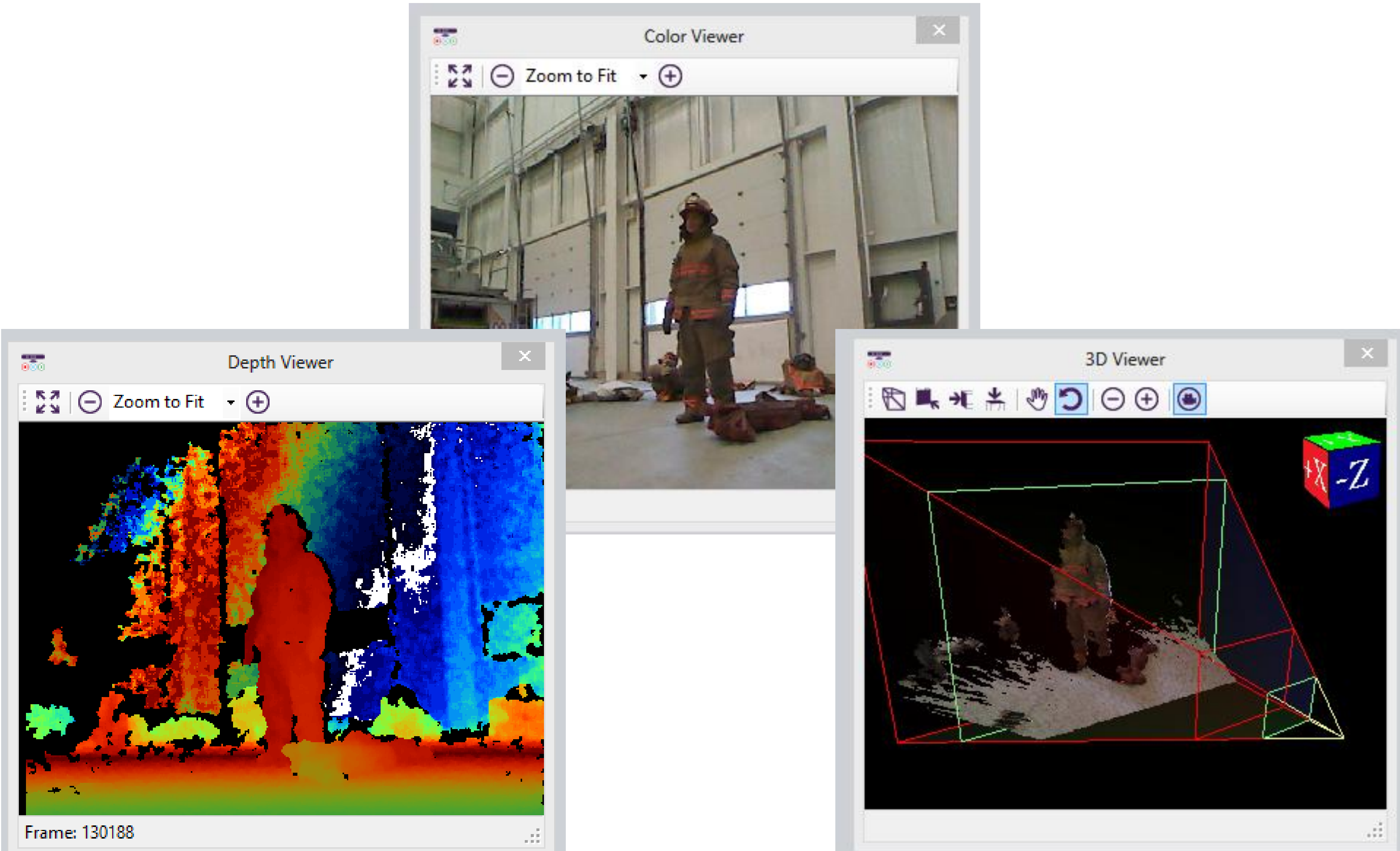
- Measurement Tools:
  – Microsoft Kinect System

What is the Kinect system?

How does the Kinect system work?



How does the Kinect system work?



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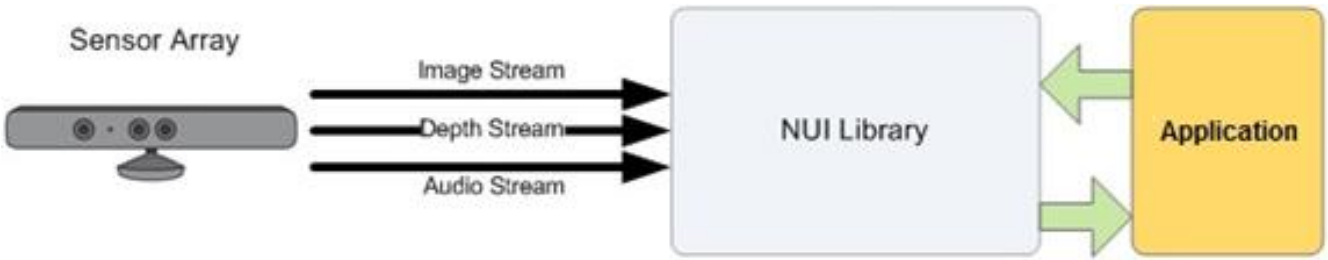
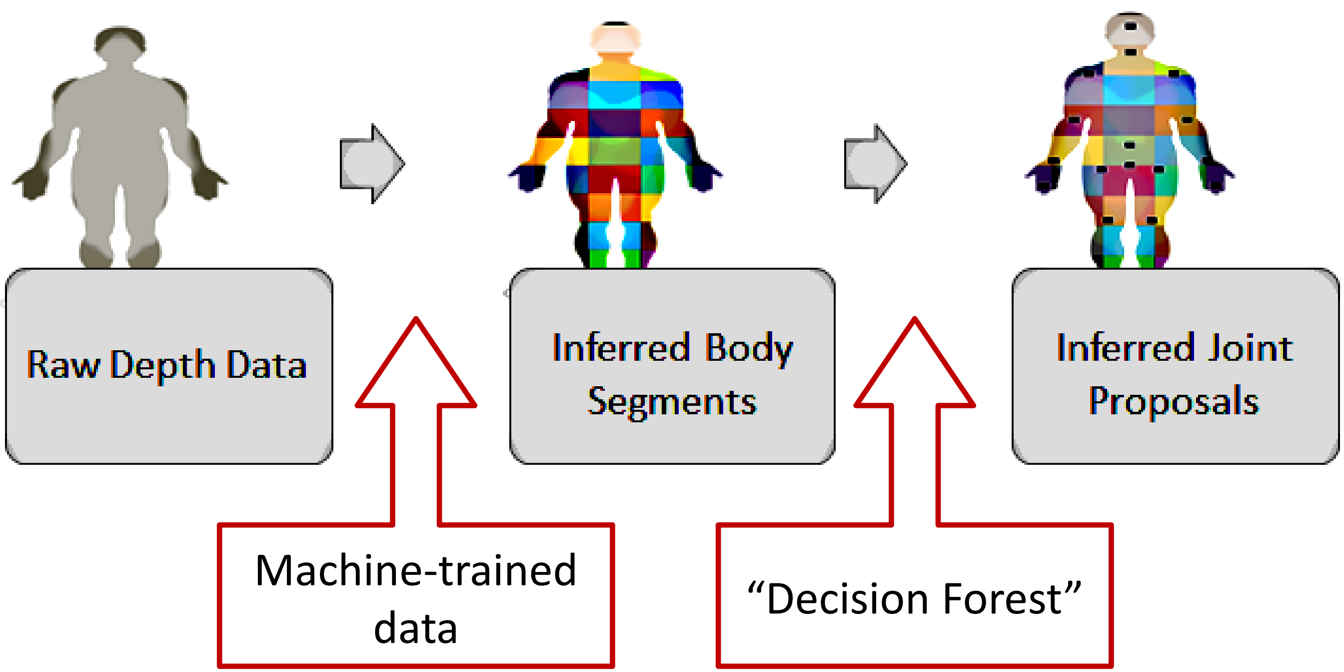
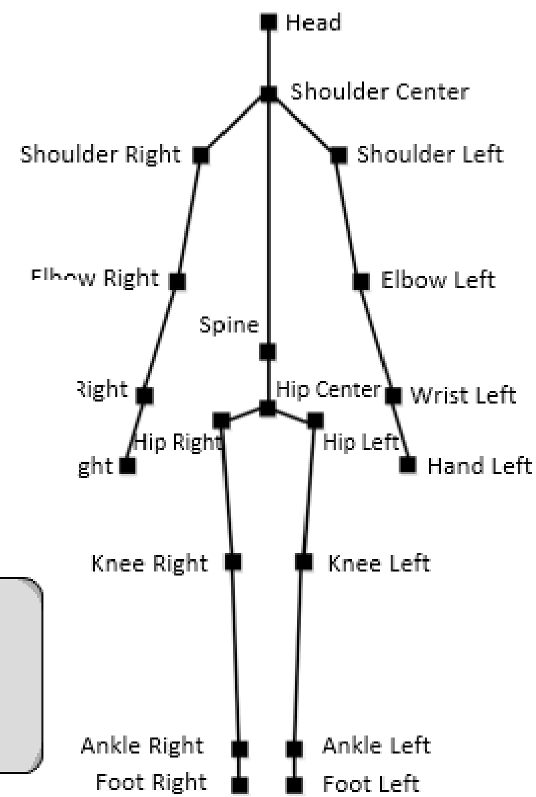






Kinect for Windows SDK Programming Guide

Skeleton Demo from Depth Data

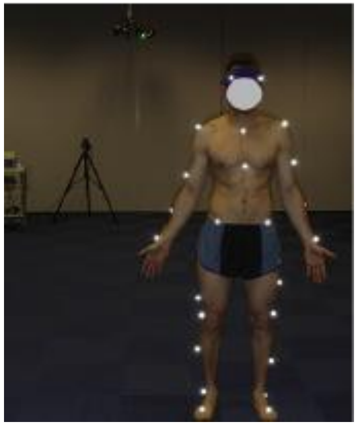
Kinect vs. Vicon Validation

Clark et al. (2012)

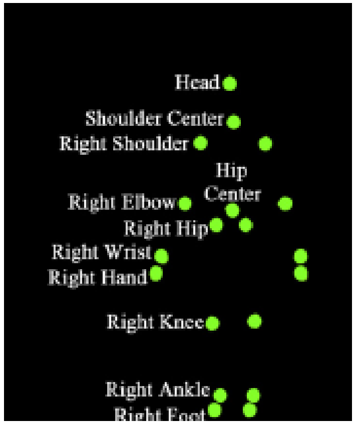
- Three balance tests (forward reach, lateral reach, and single-leg eyes-closed standing balance test)
- Compared select joint angles and landmarks
- Concurrent validity: Pearson's correlations r=0.96 ± 0.04; range 0.84-0.99

Dutta (2011)

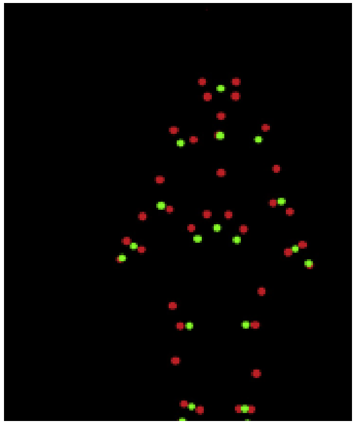
- 104 target (0.1m cubes) locations within a distance of 1-3 m.
- Root mean-squared errors were:
- x-axis: 0.0065 m (0.0048 m),
- y-axis: 0.0109 m (0.0059 m),
- z-axis: 0.0057 m (0.0042 m)



Vicon



Kinect



Combination

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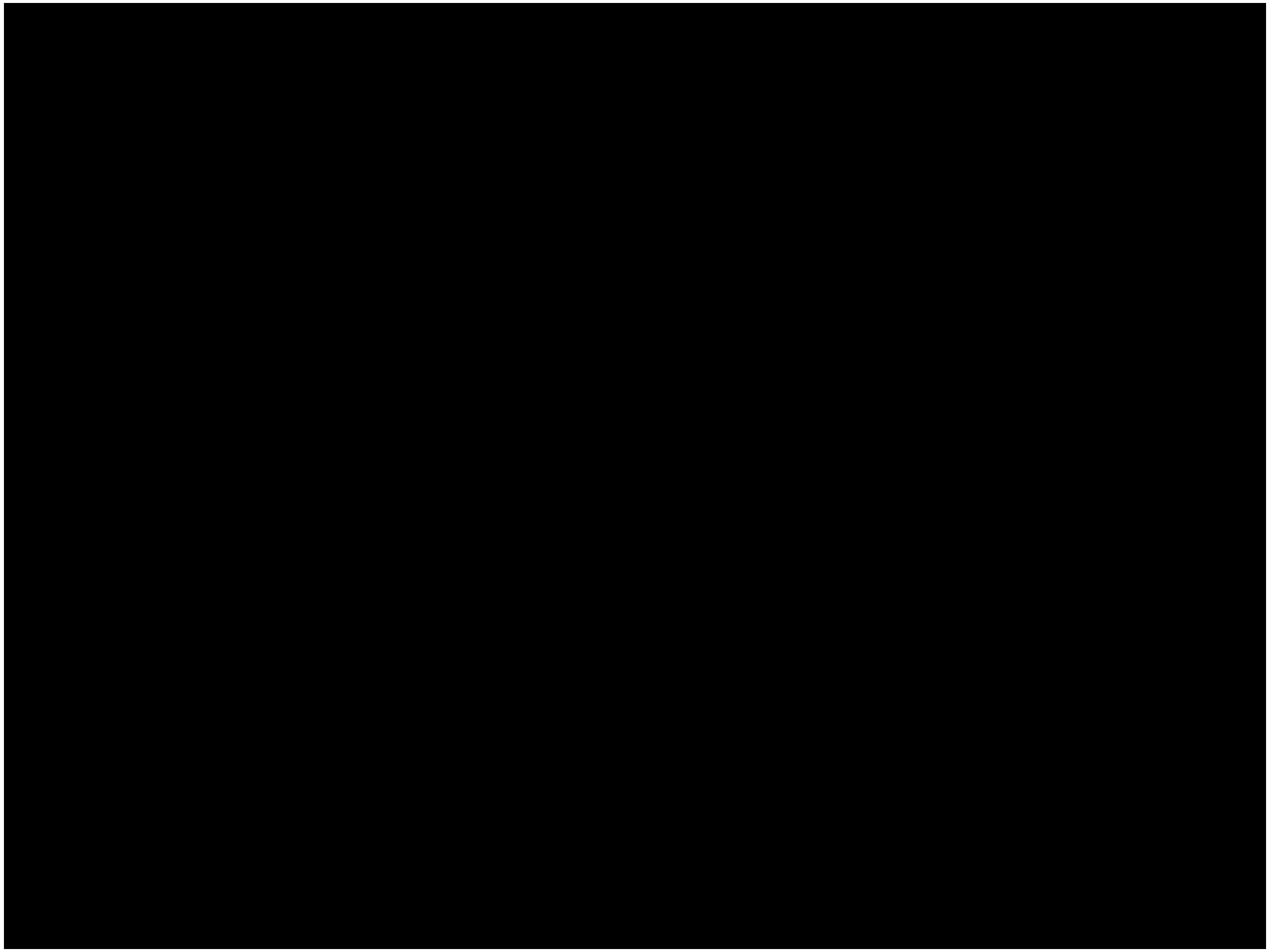
Pros and Cons of the Kinect System

Pros	Cons
Field-friendly	Less accurate than some systems
Easy to set-up	Challenges with 360^o view
Markerless	Skeleton lag
No calibration required	Max sampling rate of 30 Hz (inconsistent)
Instantaneous data output	Occlusion issues
Free development toolkit	
Integration of multiple kinect systems	
Cost	

Movement Patterns of Firefighters



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Kinect and Jack

Jack, Siemens PLM Solutions http://www.youtube.com/watch?v=_JIkoWV4yFo

Firefighter Movement Analysis

Purpose:

- Phase I:
  - To record the breadth of postures used to complete three common firefighter tasks
- Phase II:
  - To evaluate a subset of male and female firefighters as they perform the high-rise pack lift task using gaming and simulation technology

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Firefighter Movement Analysis

Methods:

- Recruitment to Hamilton Training Facility:
  - Internal recruitment through Rob D'Amico
  - Volunteer fit-for-duty firefighters (inclusion criteria)
  - On-duty firefighters (shift coverage was arranged)

- Data Collection Location:
  - Hamilton Firefighter Training Facility

Firefighter Movement Analysis

Protocol:

- Groups of 7-12 firefighters/testing day
- Ethics and study protocol review
- Anthropometric/Demographic Data:
  - height and weight
  - age, sex, and tenure
  - Additional (Kathryn Sinden):
    - Work Limitations Questionnaire -WLQ 25,
    - Organizational Policies and Practices Questionnaire – OPP 11,
    - Patient Specific Functional Scale - PSFS

Firefighter Movement Analysis

Protocol:

- Firefighters wore bunker gear, including helmet and self-contained breathing apparatus (22.7 kg)

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Protocol:

- Tasks: (Candidate Physical Ability Test)
  1) Hose Drag (6.1kg)
  2) Hose Pull (6.1kg)
  3) High-rise pack lift and carry (19.5kg)

Firefighter Movement Analysis

Protocol:

- Standardized Hose Position
  - Starting box: 0.4 m x 0.3 m
  - Nozzle/pack position was 0.3 m to the right and 0.2 m in front of the box center (for right handed participants)

Firefighter Movement Analysis

Protocol:

- Standardized Hose Position
  - Starting box: 0.4 m x 0.3 m
  - Nozzle/pack position was 0.3 m to the right and 0.2 m in front of the box center (for right handed participants)

- Standardized Camera Position
  - Task 1 and 2: Kinect was 3.65 m in front of starting position
  - Task 3: Kinect was 3.35 m from start position at a 15 ^{o} offset
  - Kinect Height: 0.5 m

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Phase I
Video Observation Analysis

	Description	Task 1	Task 2	Task 3
Posture	Initial body posture (kneeling, squatting, stooping, other)	✓	✓	✓
Posture	# Hands used at pick-up (one hand, two hands)	✓	✓	✓
Posture	Hose position during hose drag (over the shoulder, pistol grip, other)	✓		
Posture	# Hands used during hose drag (one hand, two hands)	✓		
Posture	Body posture during hose pull (kneeling, squatting, stooping, standing)		✓	
Posture	Assymetry of high rise pack lift (none, slight, significant)			✓
Posture	High-rise pack movement to shoulder (slide, flip, swing across body)			✓
Time (ms)	Initial hand on hose	✓	✓	✓
Time (ms)	Gait initiation	✓		✓
Time (ms)	Hand on hose after three hose pulls		✓	

Phase I
Video Observation Analysis

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Posture	Hose position during hose drag (over the shoulder, pistol grip, other)	✓		
Posture	# Hands used during hose drag (one hand, two hands)	✓		
Posture	Body posture during hose pull (kneeling, squatting, stooping, standing)		✓	
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Time (ms)	Initial hand on hose	✓	✓	✓
Time (ms)	Gait initiation	✓		✓
Time (ms)	Hand on hose after three hose pulls		✓	

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Phase I
Video Observation Analysis

Data Analysis:

- Descriptive statistics
  - Anthropometrics, demographics, posture
- Chi-squared analysis for associations between:
  - body posture and
  - Categories for: age, sex, height, weight, BMI, tenure, and job type
- Multivariate stepwise regression to predict BMI using video observation outcome measures
  - (e.g. body posture, number of hands, asymmetry, task time).

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Phase I
Video Observation Analysis

Results:

– Anthropometric and demographic data:

		Age (years)		Weight (kg)		Height (cm)		Tenure (years)	
	N	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**
Male	42	44.0	8.8	96.5	11.1	179.8	8.9	15.9	8.7
Female	6	36.0	5.4	70.0	12.6	167.7	4.3	7.0	3.6
Average	**48**	**43.0**	**8.8**	**93.2**	**14.2**	**178.3**	**9.4**	**14.8**	**8.7**

Phase I
Video Observation Analysis

Results:

– Descriptive statistics for body posture:

		Posture			
Task Number	**Task Description**	**Kneeling**	**Squatting**	**Stooping**	**Other/ Standing**
1	Hose Pick-Up	10	9	29	0
2	Hose Pick - Up	27	3	18	0
2	Hose Pull	23	0	12	13
3	High Rise Pack Lift	30	5	11	2

Phase I
Video Observation Analysis

Results:

- Chi-squared analysis:
  - Task 3: initial body posture vs. age ($p = 0.034$)
  - All other Chi-squared analyses showed no associations in posture based on age, sex, tenure, height, weight, or BMI.

- Multivariate regression to predict BMI:
  - Task 1: Hose drag posture when walking

    ($p = 0.038$), $R = 0.300$
  - Task 3: Task time

    ($p =0.037$), $R = 0.302$

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Phase I
Video Observation Analysis

Chi-squared analysis:

- Increased use of kneeling and stoop postures

			Task 3 Initial Body Posture				
			Kneeling	Squat	Stoop	Other	Total
Age Categories	20-29	Count	2	2	1	2	7
		% within Age Category	28.6%	28.6%	14.3%	28.6%	100.0%
	30-39	Count	5	1	2	0	8
		% within Age Category	62.5%	12.5%	25.0%	0.0%	100.0%
	40-49	Count	16	2	4	0	22
		% within Age Category	72.7%	9.1%	18.2%	0.0%	100.0%
	50-59	Count	7	0	4	0	11
		% within Age Category	63.6%	0.0%	36.4%	0.0%	100.0%
	Total	**Count**	**30**	**5**	**11**	**2**	**48**
		% of Total	**62.5%**	**10.4%**	**22.9%**	**4.2%**	**100.0%**

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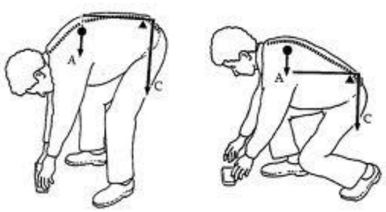
Phase I

Video Observation Analysis

Discussion:

- Aside from the association between Task 3 Initial Body Posture and Age, preliminary analysis did not show strong associations between body posture and firefighter characteristics
  - Future analyses should consider multinomial logistic regression and/or cluster analysis

- Several postures exhibited potentially harmful postures including stoop lifting and asymmetric lifting
  - Ergonomic training for firefighters may be needed to encourage avoidance of dangerous postures



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Phase I
Video Observation Analysis

Limitations:

- A small sample of female firefighters was recruited; however, the females were well represented relative to the cohort size.
- Only one trial for each firefighter was observed and analyzed.
    - Within-firefighter posture variability cannot be observed

Phase I
Video Observation Analysis

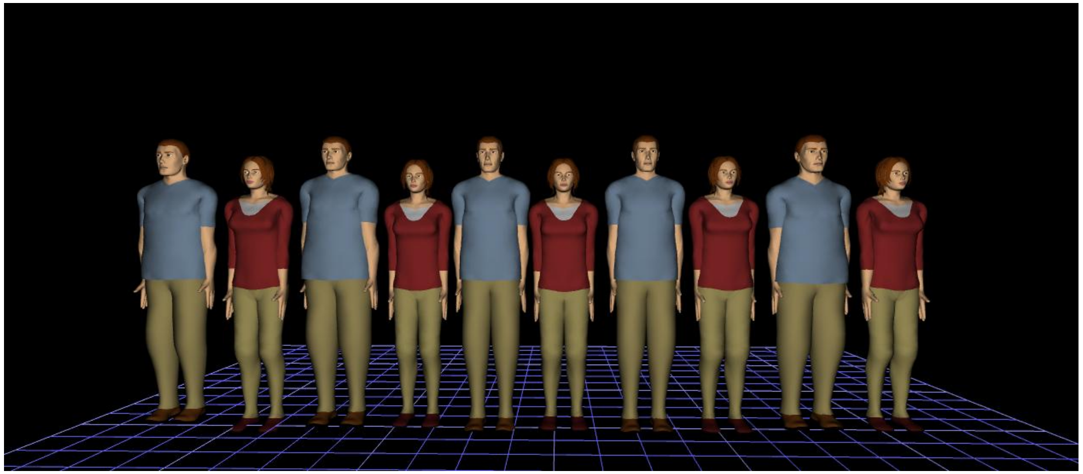
Conclusion:

– No single posture is adopted by all firefighters to perform a given task
  - Age may be an important consideration with respect to preferred working postures.
  - Ergonomic analyses of postures is needed to recommend most appropriate postures.

Phase II
Ergonomic Simulation Analysis

Purpose:

- To evaluate a subset of male and female firefighters as they perform the high-rise pack lift (Task 3) using gaming and simulation technology
  - » Task 3 was selected due to the magnitude of the load to be lifted (19.5 kg)



Phase II
Ergonomic Simulation Analysis

Methods:

- Purposive sampling based on:
  - Sex (5 male, 5 female)
  - Age
  - Height
  - Weight
  - Lift Posture

		Age (years)		Height (cm)		Weight (kg)		Tenure (years)	
	N	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Male	5	39.20	12.48	180.34	7.41	100.88	19.45	12.20	10.99
Female	5	36.60	5.86	167.18	4.62	65.50	6.83	6.20	3.40
Average	10	37.90	9.29	173.76	9.05	83.19	23.16	9.20	8.29
Cohort Average	48	**42.96**	**8.84**	**178.27**	**9.38**	**93.20**	**14.23**	**14.75**	**8.73**

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Phase II
Ergonomic Simulation Analysis

	Participant Number	Age	Weight (kg)	Height (cm)	Tenure (years)	Job Title	Initial Body Posture
Male	1	34	82.92	180.34	7.0	Firefighter	Kneeling
	2	50	134.17	182.88	22.0	Firefighter	Kneeling
	3	29	94.26	185.42	3.0	Firefighter	Stoop
	4	55	96.98	185.42	26.0	Captain	Stoop
	5	28	96.07	167.64	3.0	Firefighter	Lean
	Mean	**39.20**	**100.88**	**180.34**	**12.20**		
	STD	**12.48**	**19.45**	**7.41**	**10.99**		
Female	1	44	67.49	172.97	5.0	Firefighter	Squat
	2	33	57.97	162.56	3.0	Firefighter	Kneeling
	3	37	63.41	162.56	12.0	Firefighter	Kneeling
	4	40	76.11	170.18	5.5	Firefighter	Stoop
	5	29	62.50	167.64	5.5	Firefighter	Squat
	Mean	**36.60**	**65.50**	**167.18**	**6.20**		
	STD	**5.86**	**6.83**	**4.62**	**3.40**		

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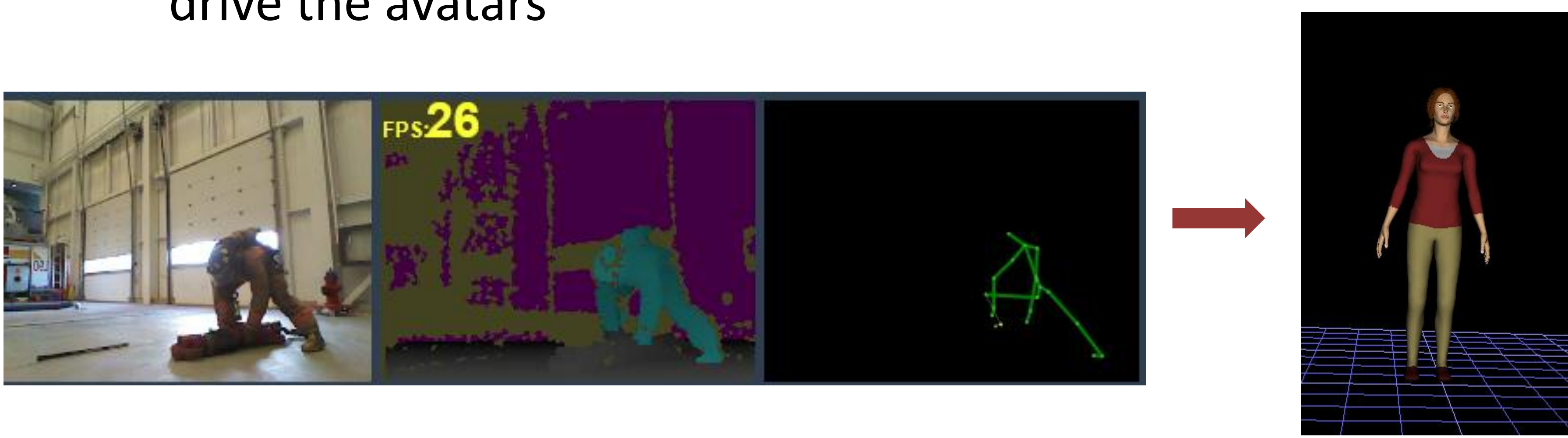
Phase II
Ergonomic Simulation Analysis

Protocol:

- Jack avatars were scaled based on sex, height, and weight of the firefighters
  - Bunker gear and SCBA were not accounted for in this analysis
- Kinect skeleton data was streamed into Jack Software to drive the avatars



Phase II
Ergonomic Simulation Analysis

Protocol:

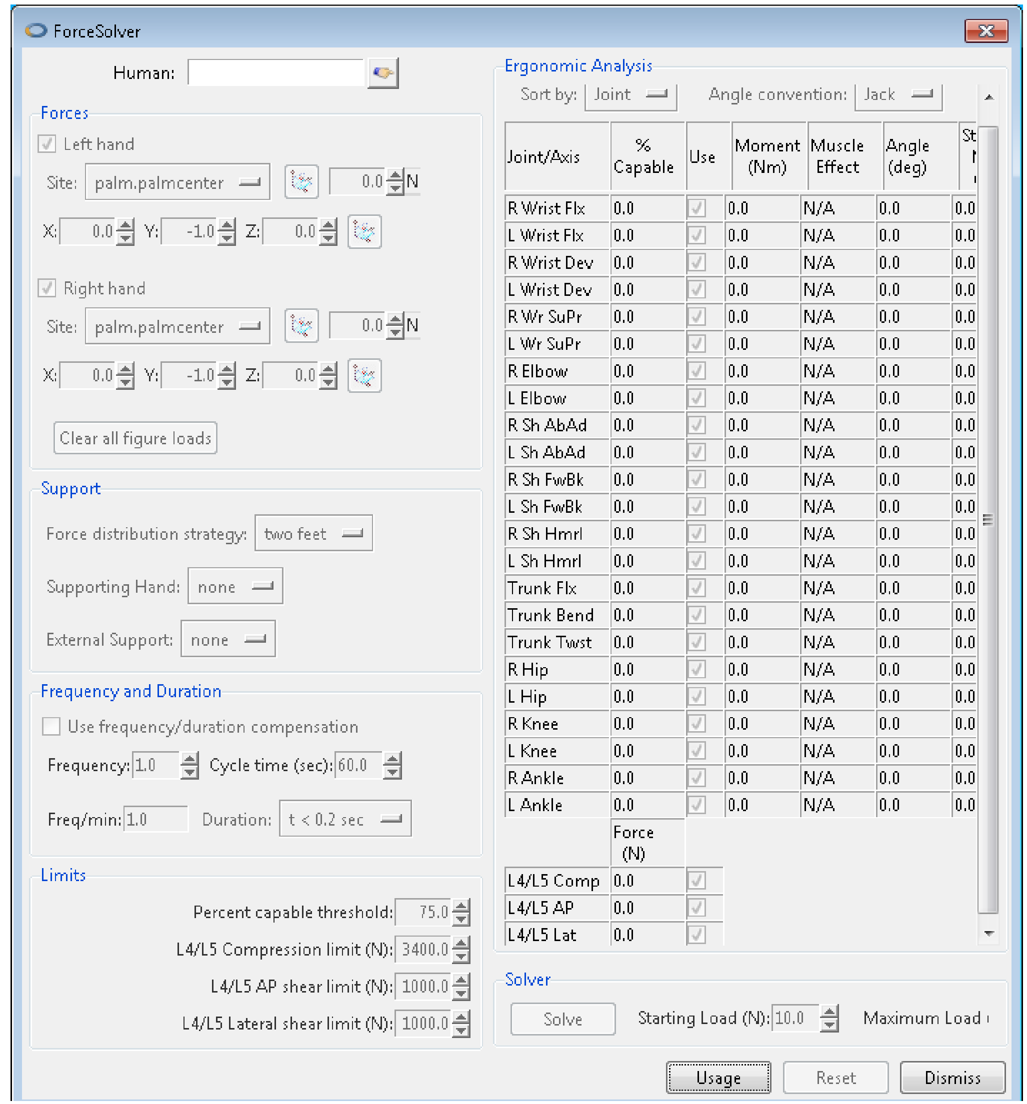
– Simulations were performed for *Task 3 Initial Body Postures* using:
  - Kinect skeleton data streaming
  - manual manipulation by expert Jack user (6 years experience)[1,2]

1. Potvin et al., 2008
2. Kajaks et al. 2011

Phase II
Ergonomic Simulation Analysis

Protocol:

- Ergonomic Analysis of initial body posture was performed within Jack, with focus on lumbar forces.
- Assumption of equal weight in hands (88.78 N per hand)



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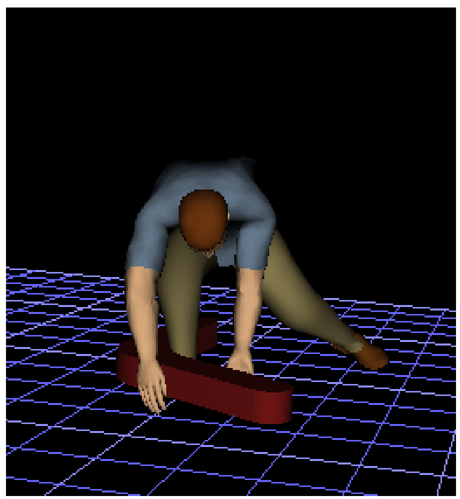
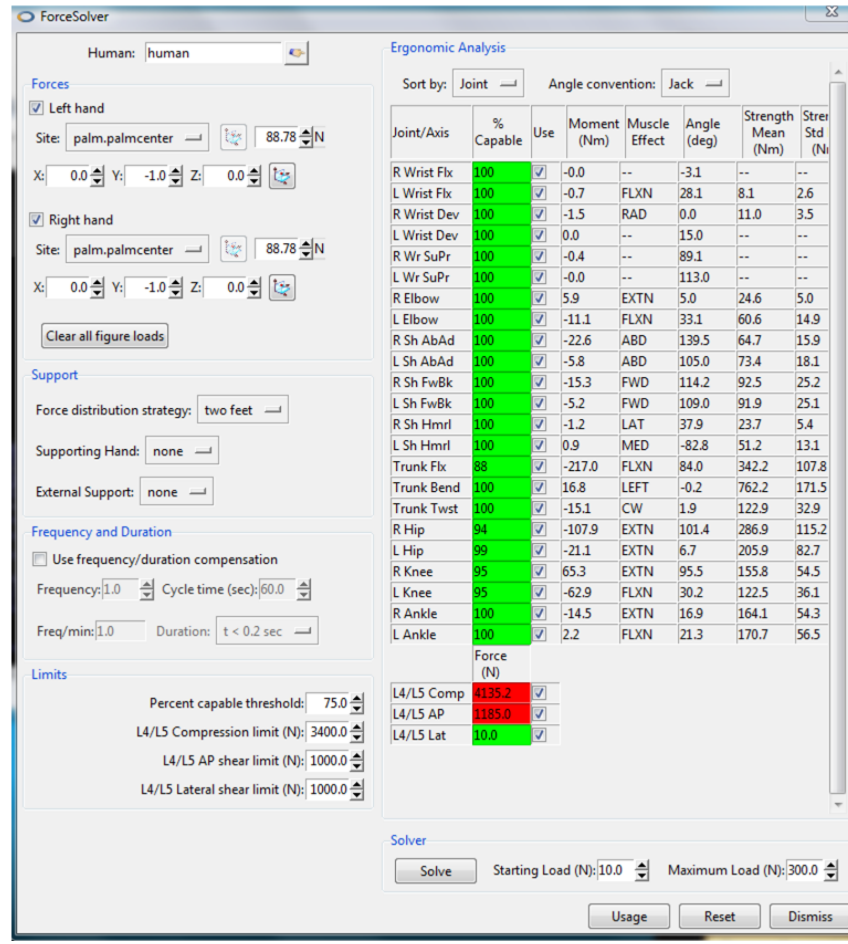
Phase II
Ergonomic Simulation Analysis





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Results

	Participant Number	Initial Body Posture	L4/L5 Comp. (N)	Acceptable Comp. Force? (3400 N)	L4/L5 Shear (N)	Acceptable Shear Force? (1000 N)	L4/L5 Lateral Force (N)	Acceptable Lateral Force ? (1000 N)
Male	1	Kneeling	3879.3	no	955.7	no	31.8	yes
	2	Kneeling	5384.5	yes	1390.2	yes	93.5	yes
	3	Stoop	4035.0	no	1197.5	no	29.6	yes
	4	Stoop	3062.7	yes	1013.5	no	-20.7	yes
	5	Lean	4135.2	no	1185.0	no	10.0	yes
	Mean		**4099.3**		**1148.4**		**28.8**	
	STD		**833.7**		**171.4**		**41.8**	
			*		*			
Female	1	Squat	3105.1	yes	941.4	yes	10.8	yes
	2	Kneeling	2611.1	yes	535.8	yes	4.4	yes
	3	Kneeling	2764.1	yes	682.1	yes	41.6	yes
	4	Stoop	2689.2	yes	746.8	yes	34.4	yes
	5	Squat	3263.6	yes	870.6	yes	22.3	yes
	Mean		**2886.6**		**755.3**		**22.7**	
	STD		**282.7**		**159.3**		**15.6**	

* = $P<0.05$

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Phase II
Ergonomic Simulation Analysis

Discussion:

- Men exhibited greater shear and compression forces than women in this subset sample

- Compared to NIOSH action limits, in this sample:
  - 3/5 men did not perform the task safely according to compression limits
  - 4/5 men did not perform the task safely according to shear limits

Phase II
Ergonomic Simulation Analysis

Discussion:

- Women appear to adopt safer lifting postures than men when lifting high-rise packs
  - However, more postures, using a larger sample size, need to be assessed to determine if there is a trend in performance safety
  - Literature shows that female firefighters are at a greater risk of injury[1]

Liao et al., 2001

Phase II
Ergonomic Simulation Analysis

Limitations:

- Simulations did not include bunker gear and SCBA (net weight of 22.7 kg)
  - Work is in progress to identify optimal positioning of loads to properly simulate gear

- Quality of the Kinect data was compromised due to the position of the high-rise pack in front of the firefighter
  - Manual manipulation of avatar was required to complete posturing

Future Research with the Kinect

- Firefighters:
  - Kinect validation with bulky clothing
  - Simulation of bunker gear and SCBA
- Firefighters and other contexts:
  - Ergonomic training modules
  - Rehabilitation tools
  - Applied research with multiple Kinects (e.g. older driver research)

Kinect 2.0

Skeleton
FPS: 31.13
Skeleton
Orientation
Muscle+Force
60
Heartrate
Expression

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The **MOVE** group…

Movement Analysis: **O**ccupationally **V**alid **E**valuation

- A research group with the interest and expertise to advance the area of field-based motion analysis.
- Group Members:

Tara Kajaks

Kathryn Sinden

Dr. Joy MacDermid

Dr. Brenda Vrkljan

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Thank You

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