

# Evaluation of the FSA™ Hand Force Measurement System



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# Agenda



- Background
- Objective of the Study
- Method
- Results
- Discussion



# Force: Risk Factor for UEMSDs



- Use of excessive hand force at work may cause upper-extremity musculoskeletal disorders (NIOSH, 1997).

Body part		Risk factor	Evidence*
Neck/Shoulder		Repetition	++
		Force	++
		Posture	+++
		Vibration	+
Elbow		Repetition	+
		Force	++
		Posture	+
		Combination	+++
Hand/Wrist	CTS	Repetition	++
		Force	++
		Posture	+
		Vibration	++
	Tendinitis	Combination	+++
		Repetition	++
		Force	++
		Posture	++
		Combination	+++

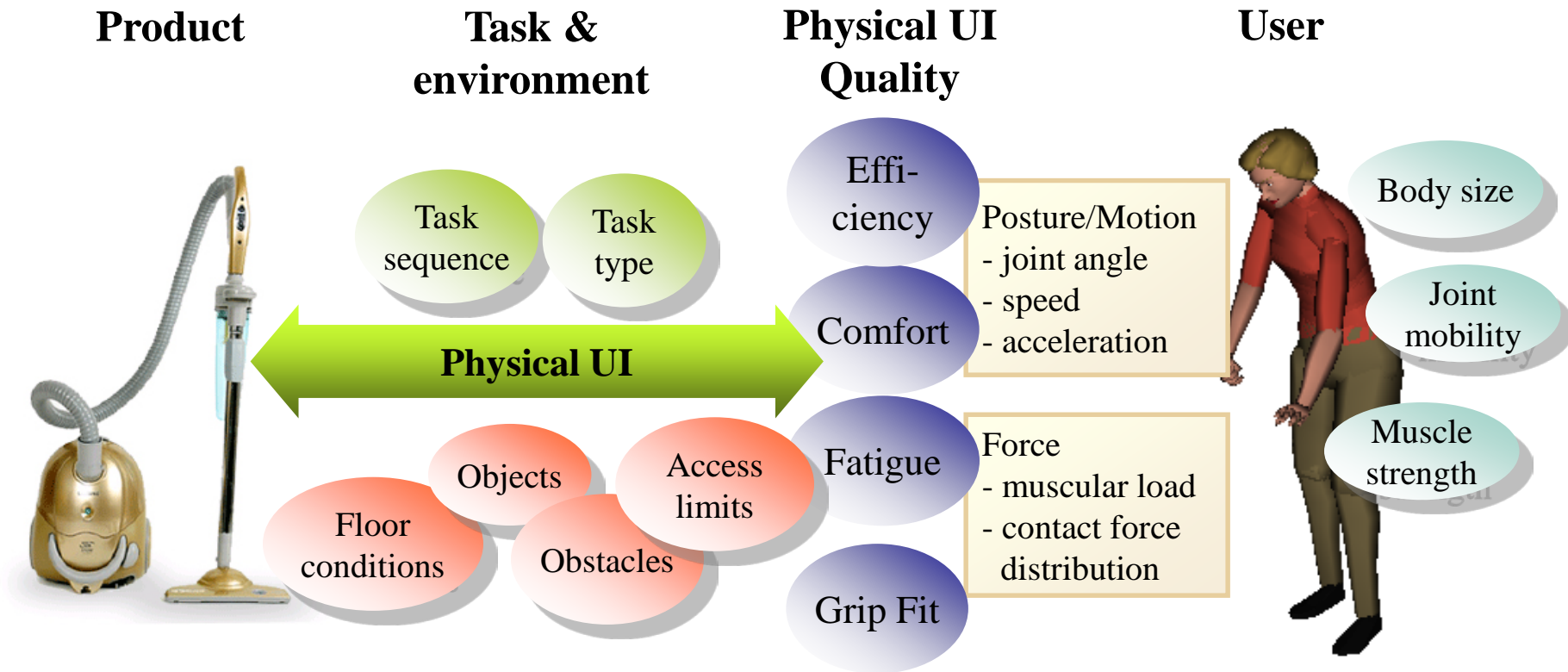
(Note) +++: strong evidence; ++: evidence, +: insufficient evidence



# Force: Design Factor in Product Interface



- ❑ The level of force applied and the distribution of contact force affect the quality of physical user interface.



# Hand Force Measurement Systems

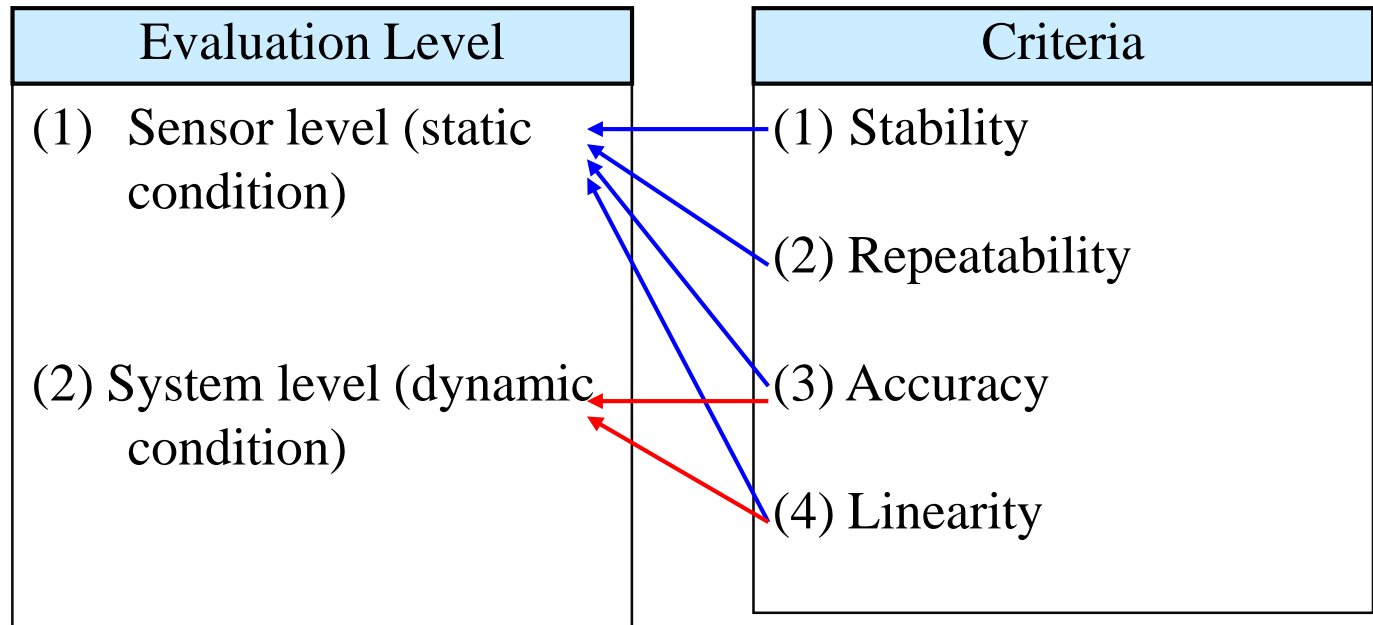


	Hand Dynamometer	FSA (Force Sensitive Application)
Sensor	<ul style="list-style-type: none"> <li>● Strain gauge</li> </ul>	<ul style="list-style-type: none"> <li>● Force sensitive resistor (FSR)</li> </ul>
Measurement	<ul style="list-style-type: none"> <li>● Composite forces applied on the handle</li> </ul>	<ul style="list-style-type: none"> <li>● Individual contact forces transferred to the surface of the product</li> </ul>
Product evaluation	<ul style="list-style-type: none"> <li>● Low applicability</li> </ul>	<ul style="list-style-type: none"> <li>● High applicability</li> </ul>
Performance	<ul style="list-style-type: none"> <li>● Accuracy: error &lt; 0.0002 kgf</li> <li>● Stability &amp; repeatability: CV &lt; 1%</li> </ul>	<ul style="list-style-type: none"> <li>● Lack of comprehensive understanding</li> </ul>

# Objective of the Study



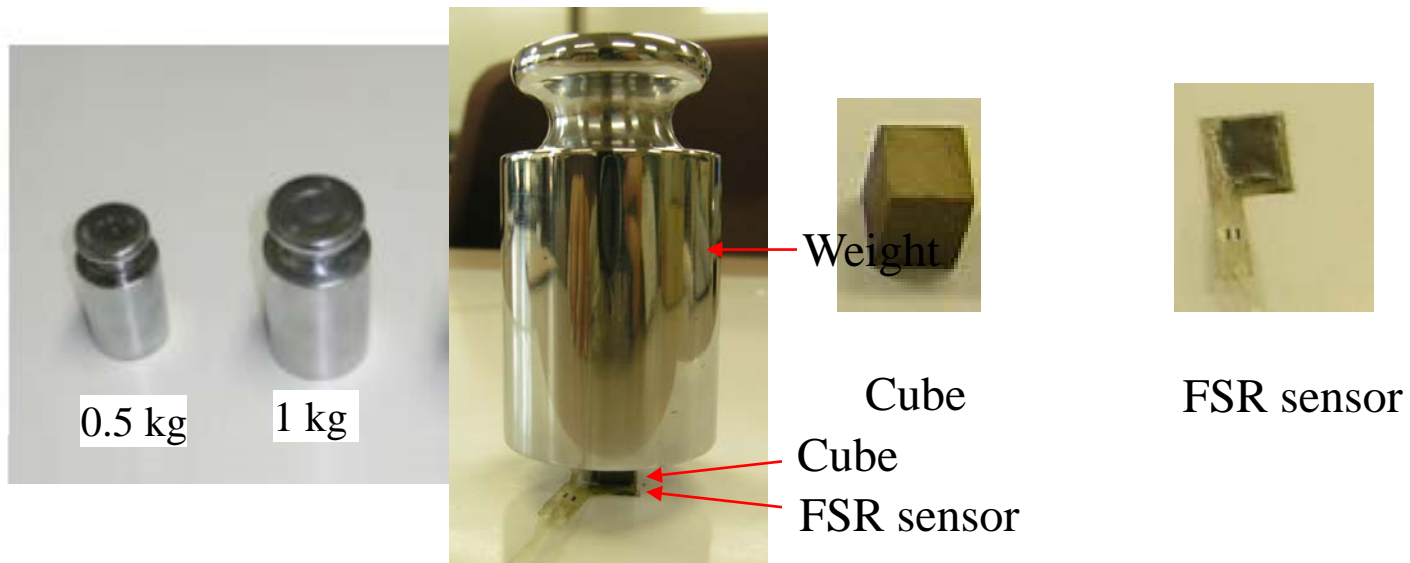
- ❑ Evaluate the FSA system in terms of stability, repeatability, accuracy, and linearity at the sensor and system levels.



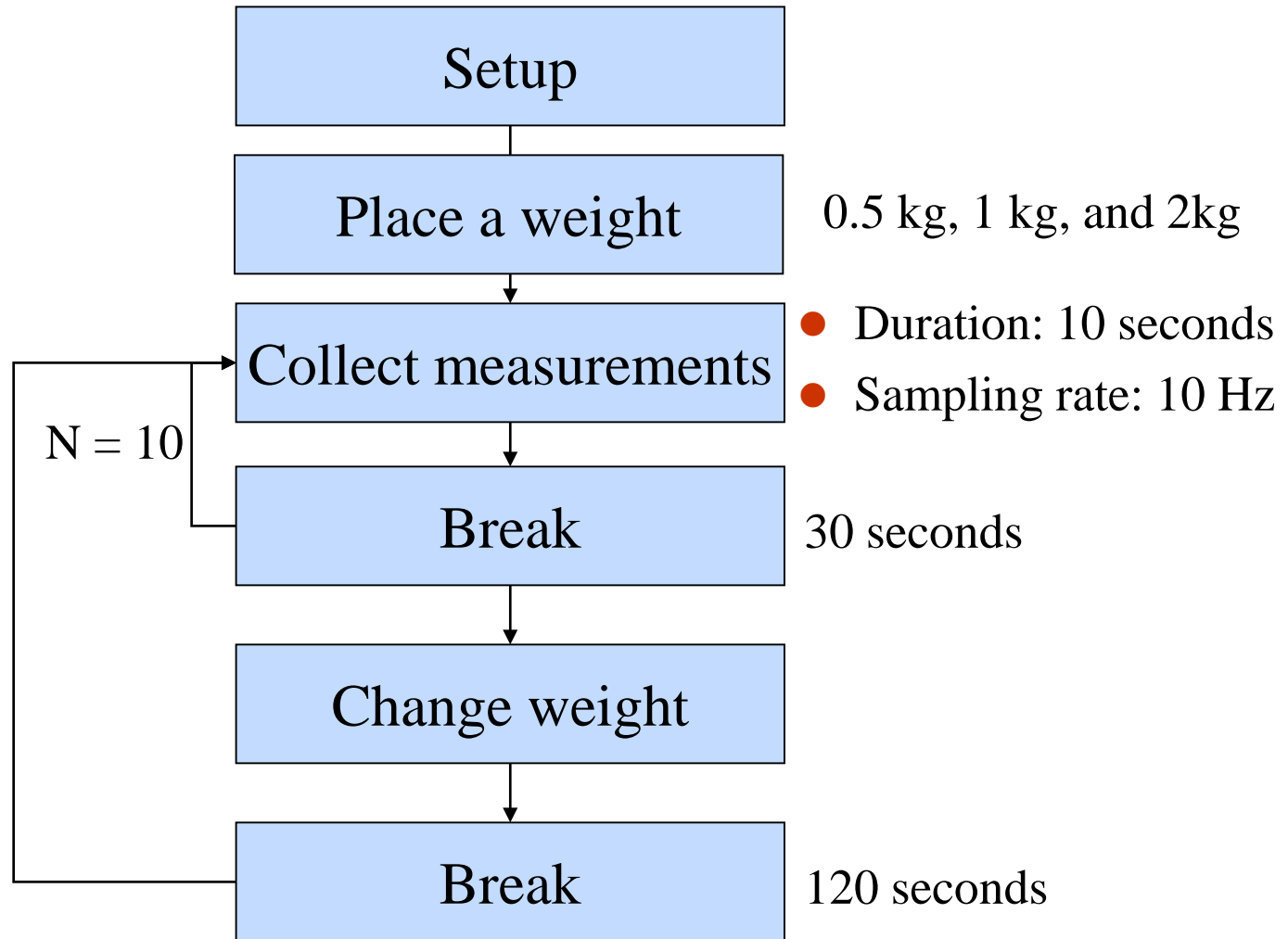
# Method: Sensor Level Evaluation



- ❑ Sensor performance evaluation using 3 weights (0.5 kg, 1 kg, 2 kg)
- ❑ To keep the contact area same, a 0.24-inch<sup>3</sup> cube (0.6 g) was placed between a weight and the sensor.



# Sensor Level Evaluation Process











# System Level Evaluation

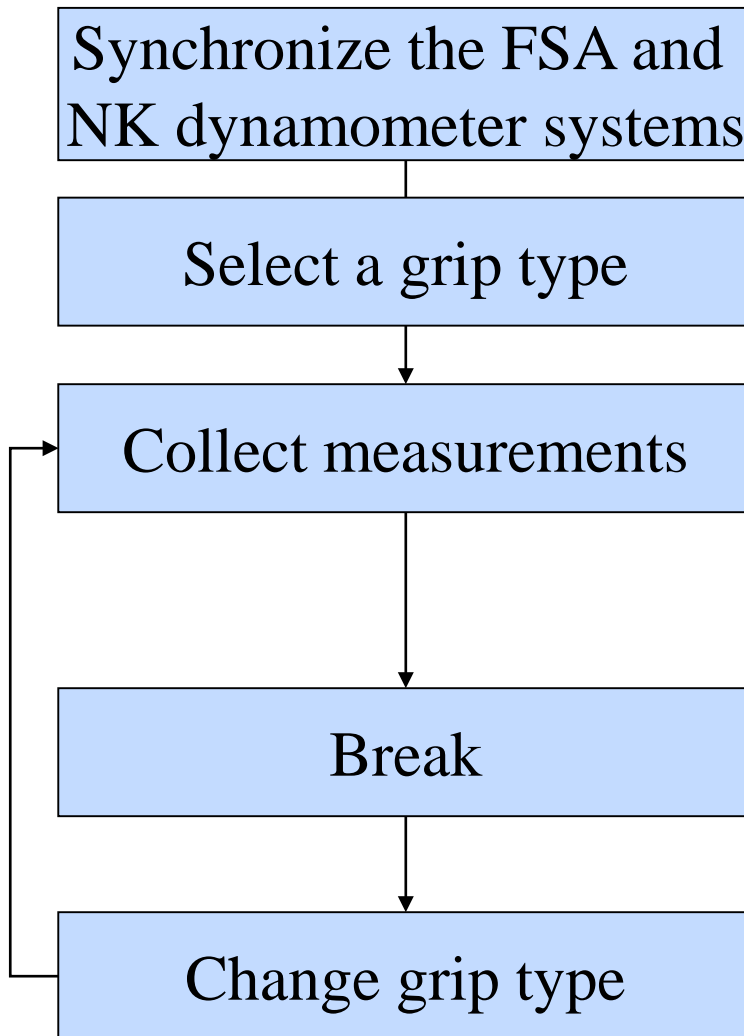


- Sensors were attached on the palmar side of the glove.

Pulp press (1 sensor)	Pulp pinch (2 sensors)	Power grip (18 sensors)
		
		

- Compared values from the FSA with those from the NK<sup>TM</sup> dynamometer (considered as a gold standard).

# System Level Evaluation Process



The clocks of two computers synchronized by AboutTime™

Press, Pinch, and Grip

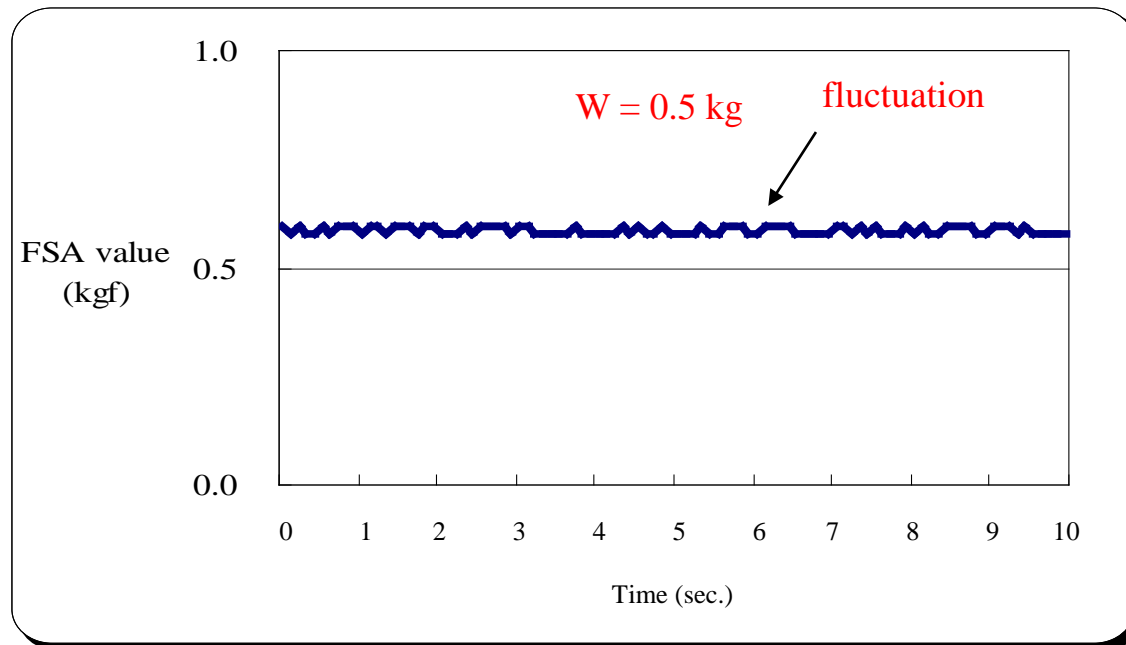
- Repetition = 3 exertions
- Peak force controlled within measurement range: pulp press = 2, pulp pinch = 4; power grip = 25 kgf)

120 seconds

# Evaluation Criteria



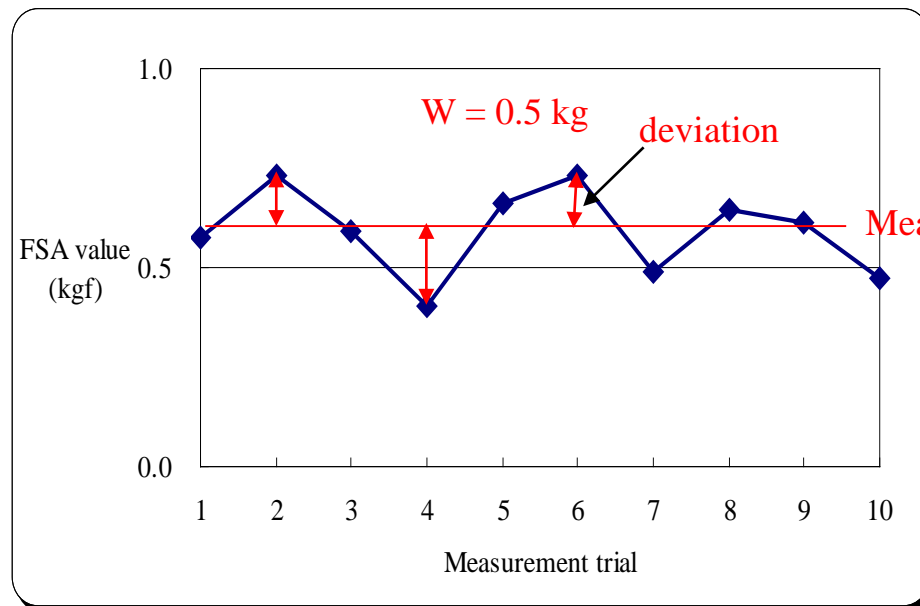
Criteria	Definition	Metrics
Stability	Fluctuation of measurements under a constant force	Coefficient of Variation (CV = SD/mean)
Repeatability	Agreement between repeated measurements under the identical condition	Coefficient of Variation (CV)
Accuracy	Difference between the measurement and true value	- Mean difference (MD) - Standard error (SE)
Linearity	Linear relationship between measurements and true values	$R^2$





# Evaluation Criteria

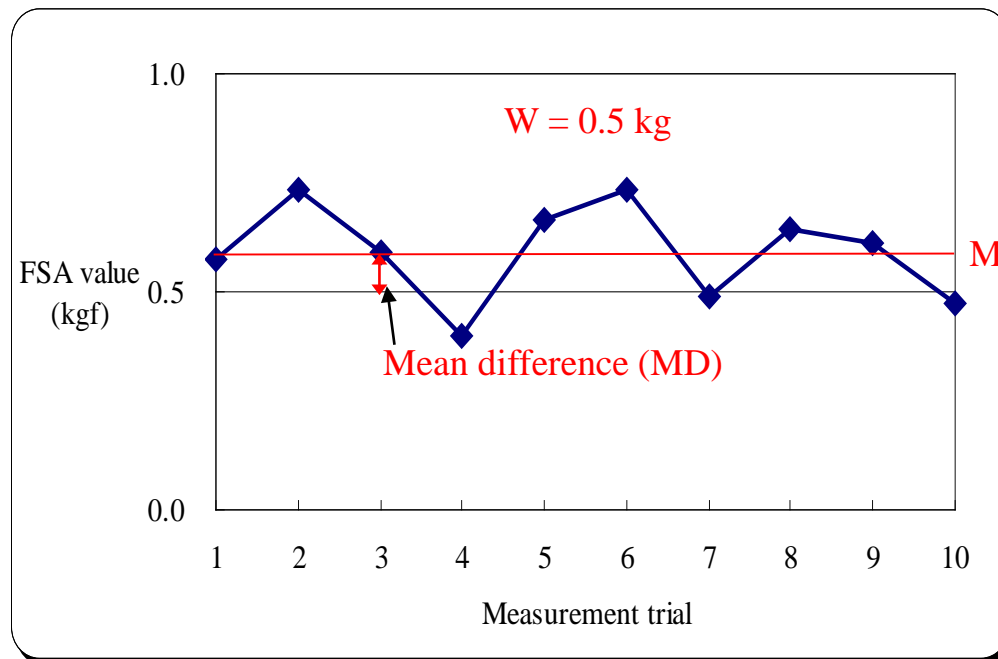
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# Evaluation Criteria

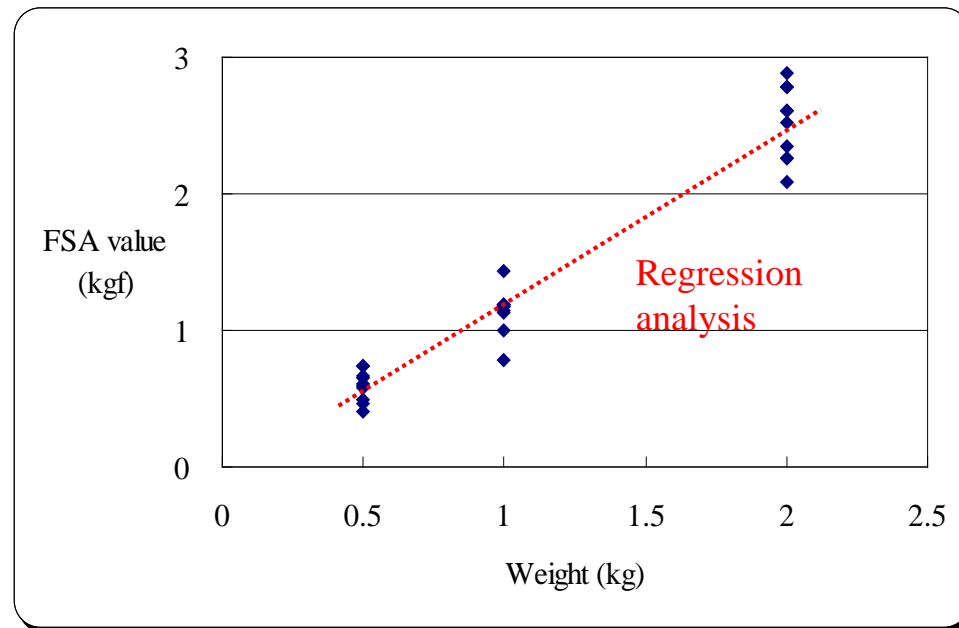
Criteria	Definition	Metrics
Stability	Fluctuation of measurements under a constant force	Coefficient of Variation (CV = SD/mean)
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# Evaluation Criteria

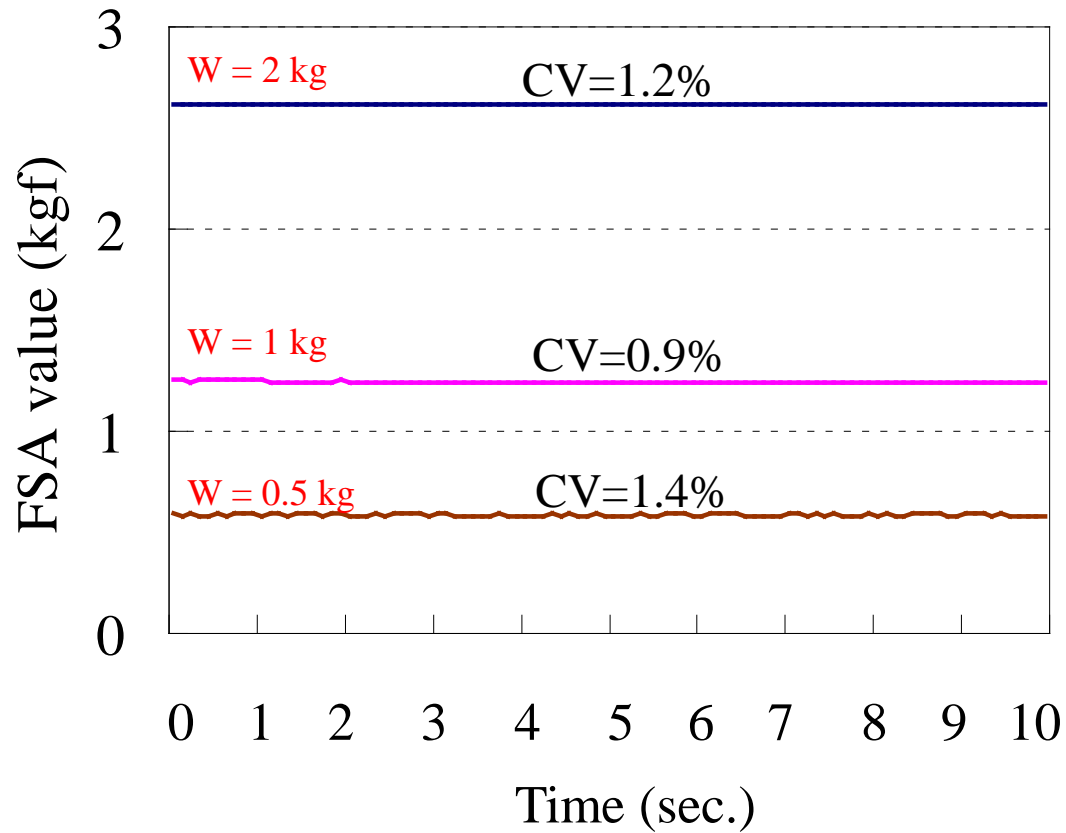
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# Sensor Level Result: Stability



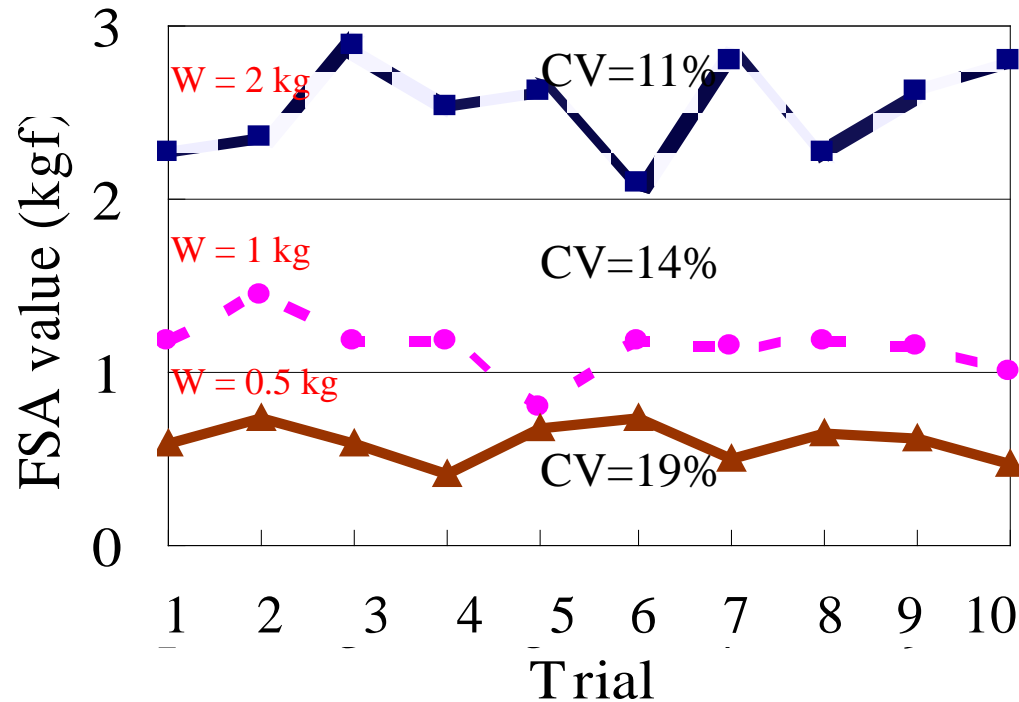
- Fair stability:  $CV = 0.9 \sim 1.4\%$



# Sensor Level Result: Repeatability



- ❑ Low repeatability:  $CV = 11 \sim 19\%$
- ❑ Repeatability decreases as weight decreases.

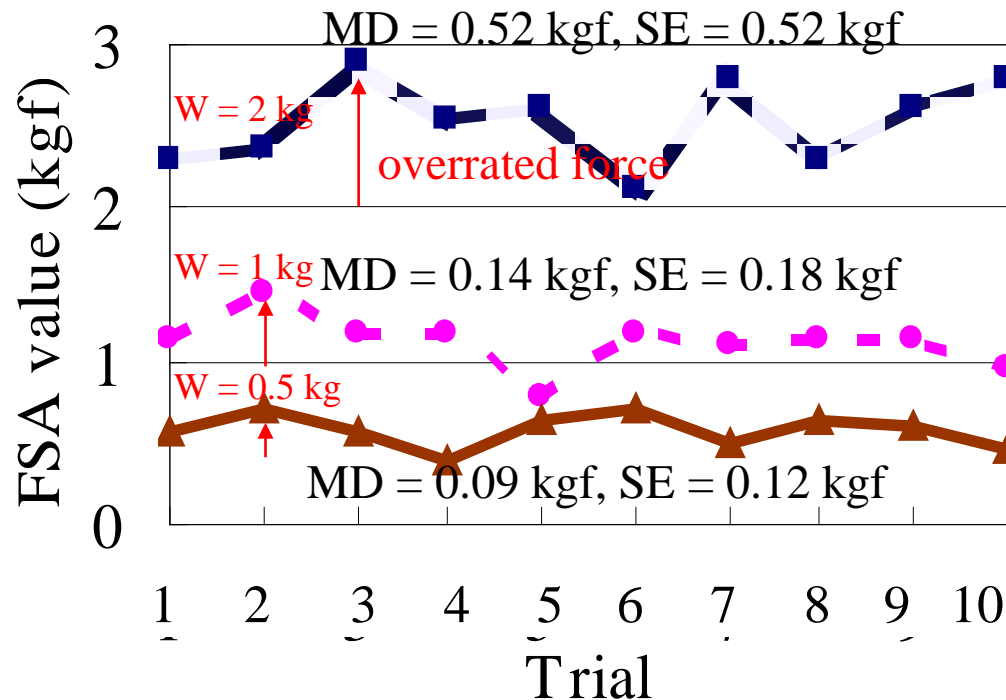




# Sensor Level Result: Accuracy



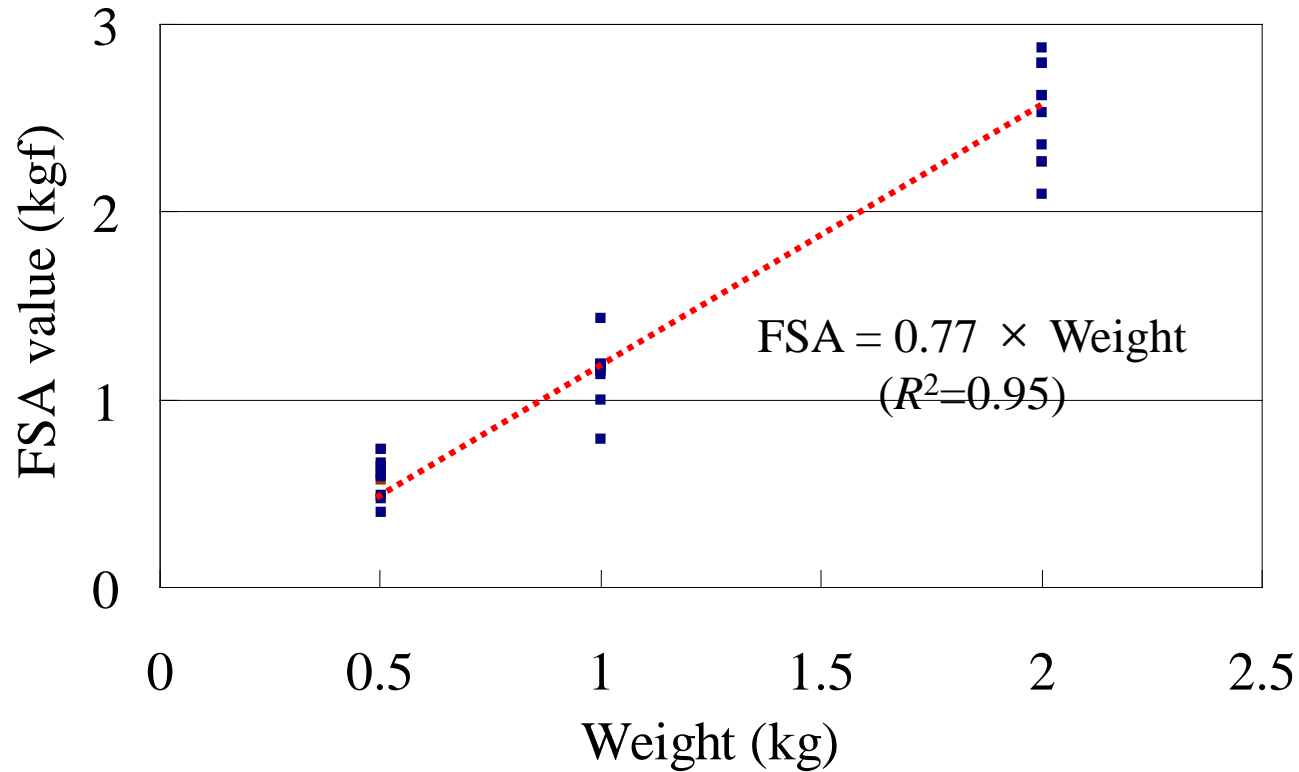
- ❑ Low accuracy: MD = 0.09 ~ 0.52 kgf, SE = 0.12 ~ 0.52 kgf
- ❑ MD and SE increase as weight increases.  
⇒ Accuracy decreases as weight increases.
- ❑ Tendency to produce overrated values.



# Sensor Level Result: Linearity



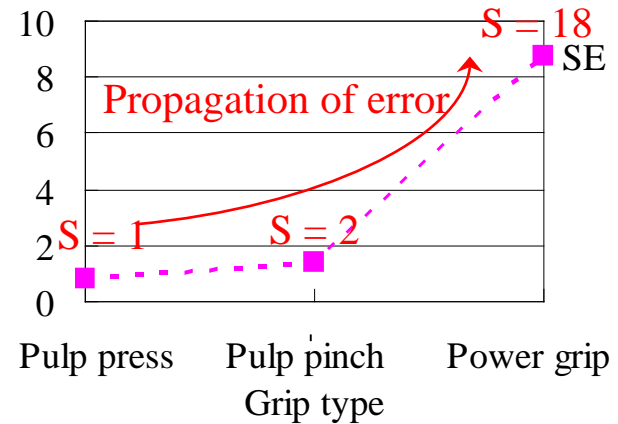
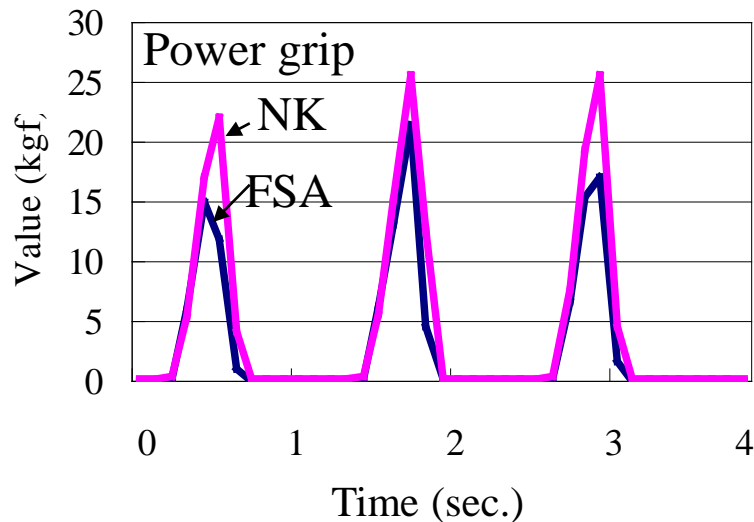
High linearity:  $R^2 = 0.95$



# System Level Result: Accuracy



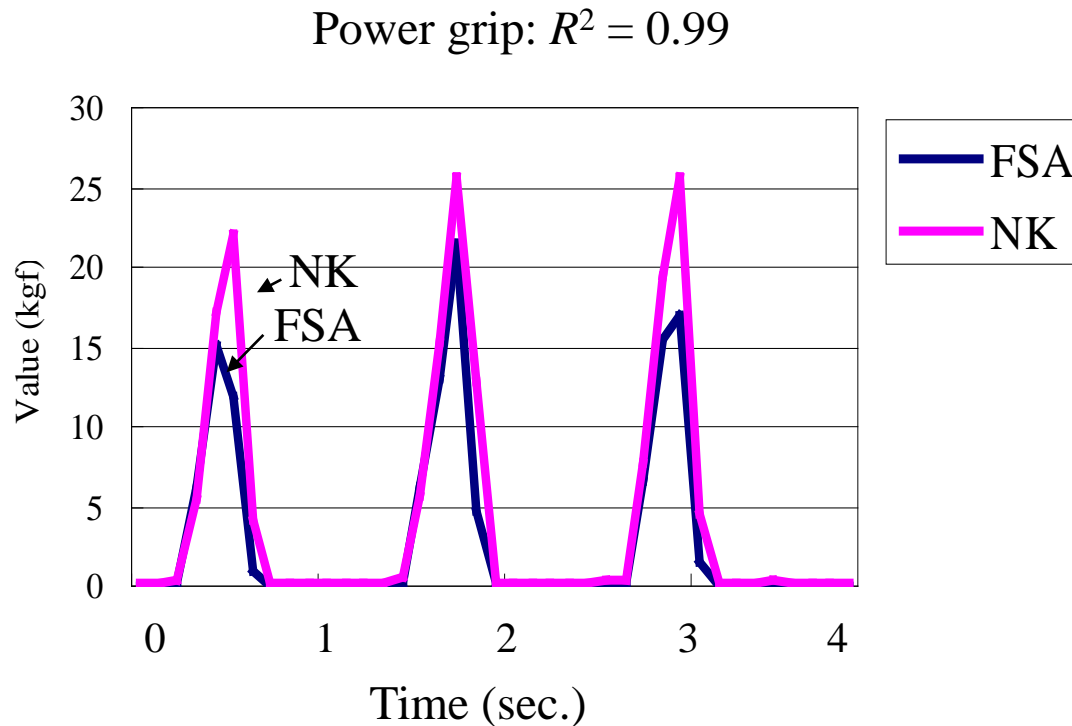
- ❑ Low accuracy: MDs = -0.09 ~ -1.49 kgf
- ❑ Negative MD values mean that the FSA system produce underrated forces than NK dynamometer.
- ❑ Propagation of error: SE at pulp press = 0.79, SE at pulp pinch = 1.4, SE at power grip = 8.73



# System Level Result: Linearity



- High linearity:  $R^2 = 0.82 \sim 0.99$  ( $p < 0.001$ )



# Discussion



Criteria	Sensor level	System level
Stability	<b>Good</b> (CV = 0.9 ~ 1.4%)	-
Repeatability	<b>Satisfactory</b> (CV = 11 ~ 19%)	-
Accuracy	<b>Satisfactory</b> (MD = 0.09 ~ 0.52 kgf)	<b>Satisfactory</b> (MD = -0.09 ~ -1.49 kgf)
Linearity	<b>Good</b> ( $R^2 = 0.95$ )	<b>Good</b> ( $R^2 = 0.82 \sim 0.99$ )



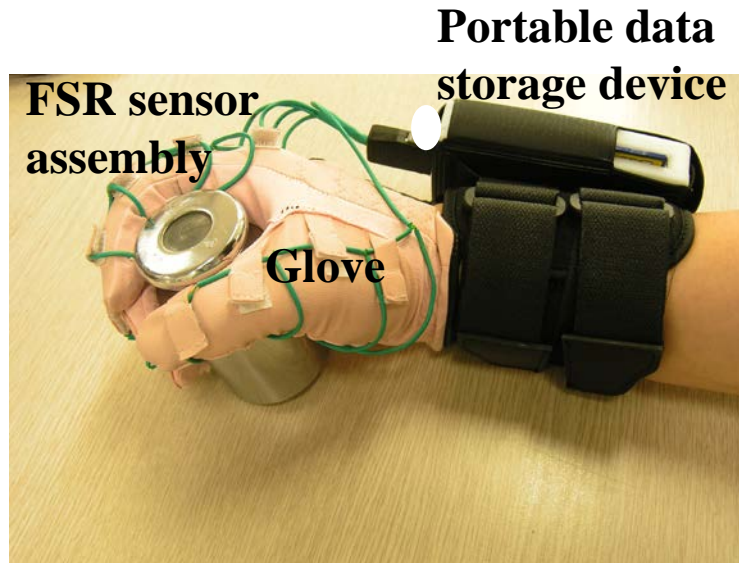
- ❑ There is discrepant experimental result in sensor and system level evaluation
  - Difference calibration and usage condition (flat floor vs. glove worn)
  - Smaller contact area due to sensor interference
- ❑ Care should be placed in data interpretation when several sensors are involved in measurement (e.g., power grip).
  - MD and SE increase as the number of sensors involved in measurement increase.
  - **Measurements should be compared and interpreted on a relative basis, not a absolute basis.**

# Follow-up Study



## Key features of i-ForceGlove

- Portable data storage device (8 hours at 10 Hz)
- 23 FSR sensors for each hand
- 4 sizes of ergonomic gloves
- Software for easy analysis & report preparation



**Hand Force Measurement System**  
File: Acquisition View: Edit: Analysis Setup: Help

Descriptive statistics

Left Hand					Right Hand				
Standard Deviation	Mean Value	Max.	Min.		Standard Deviation	Mean Value	Max.	Min.	
Ch 01: 40.74	53.37	143	11		Ch 01: 0.00	3.00	0	0	
Ch 02: 5.07	2.16	22	0		Ch 02: 28.93	34.26	66	10	
Ch 03: 178.40	130.86	447	10		Ch 03: 0.00	3.00	0	0	
Ch 04: 269.54	741.66	2000	10		Ch 04: 0.00	3.00	0	0	
Ch 05: 454.93	496.13	2000	10		Ch 05: 0.00	3.00	0	0	
Ch 06: 694.03	796.50	2000	10		Ch 06: 0.00	3.00	0	0	
Ch 07: 174.36	132.62	448	10		Ch 07: 22.16	34.36	66	10	
Ch 08: 0.00	0.00	0	0		Ch 08: 0.00	3.00	0	0	
Ch 09: 131.48	138.17	447	10		Ch 09: 0.00	3.00	0	0	
Ch 10: 4.11	1.43	16	10		Ch 10: 0.00	3.00	0	0	
Ch 11: 22.68	38.34	67	11		Ch 11: 0.00	3.00	0	0	
Ch 12: 40.25	58.97	109	10		Ch 12: 0.00	3.00	0	0	
Ch 13: 6.56	2.33	46	10		Ch 13: 0.00	3.00	0	0	
Ch 14: 64.25	27.13	46	10		Ch 14: 0.00	3.00	0	0	
Ch 15: 423.22	151.27	2000	10		Ch 15: 0.00	3.00	0	0	
Ch 16: 2.48	0.37	21	10		Ch 16: 0.57	1.07	19	10	
Ch 17: 58.25	27.19	469	10		Ch 17: 22.68	38.34	67	11	
Ch 18: 0.00	0.00	0	0		Ch 18: 40.25	58.97	109	10	
Ch 19: 22.58	34.97	70	10		Ch 19: 6.56	2.33	46	10	
Ch 20: 58.30	27.18	469	11		Ch 20: 58.25	27.13	46	10	
Ch 21: 40.25	58.97	109	10		Ch 21: 423.22	151.27	2000	10	
Ch 22: 40.00	57.90	161	10		Ch 22: 64.50	38.19	2000	10	
Ch 23: 4.12	1.51	20	10		Ch 23: 655.00	725.00	2000	10	

Total experienced time is: 30 Sec: 200 Frame

Participant: Kim ID: 123456-1234563 Experiment: Sample Test

## Analysis & report generation software

**Analysis Report**  
ID: Subj-01 Date: 2003-08-10  
Name: Jack Experiment date: 2003-06-17  
Description: Gripping task Measurement duration: 60 seconds  
Temperature: 23 Remarks: Subject01, Fast trial

Average force distribution

Left hand Right hand

Statistics

Left hand						Right hand					
Channel	Mean	Std.	C.V.	Min.	Max.	Channel	Mean	Std.	C.V.	Min.	Max.
Hand1	1.1	0.1	0.09	0	2	Hand1	1.1	0.1	0.09	0	2
Hand2	1.1	0.1	0.09	0	2	Hand2	1.1	0.1	0.09	0	2
Hand3	1.1	0.1	0.09	0	2	Hand3	1.1	0.1	0.09	0	2
Hand4	1.1	0.1	0.09	0	2	Hand4	1.1	0.1	0.09	0	2
Hand5	1.1	0.1	0.09	0	2	Hand5	1.1	0.1	0.09	0	2
Hand6	1.1	0.1	0.09	0	2	Hand6	1.1	0.1	0.09	0	2
Hand7	1.1	0.1	0.09	0	2	Hand7	1.1	0.1	0.09	0	2
Hand8	1.1	0.1	0.09	0	2	Hand8	1.1	0.1	0.09	0	2
Hand9	1.1	0.1	0.09	0	2	Hand9	1.1	0.1	0.09	0	2
Hand10	1.1	0.1	0.09	0	2	Hand10	1.1	0.1	0.09	0	2
Hand11	1.1	0.1	0.09	0	2	Hand11	1.1	0.1	0.09	0	2
Hand12	1.1	0.1	0.09	0	2	Hand12	1.1	0.1	0.09	0	2
Hand13	1.1	0.1	0.09	0	2	Hand13	1.1	0.1	0.09	0	2
Hand14	1.1	0.1	0.09	0	2	Hand14	1.1	0.1	0.09	0	2
Hand15	1.1	0.1	0.09	0	2	Hand15	1.1	0.1	0.09	0	2
Hand16	1.1	0.1	0.09	0	2	Hand16	1.1	0.1	0.09	0	2
Hand17	1.1	0.1	0.09	0	2	Hand17	1.1	0.1	0.09	0	2
Hand18	1.1	0.1	0.09	0	2	Hand18	1.1	0.1	0.09	0	2
Hand19	1.1	0.1	0.09	0	2	Hand19	1.1	0.1	0.09	0	2
Hand20	1.1	0.1	0.09	0	2	Hand20	1.1	0.1	0.09	0	2
Hand21	1.1	0.1	0.09	0	2	Hand21	1.1	0.1	0.09	0	2
Hand22	1.1	0.1	0.09	0	2	Hand22	1.1	0.1	0.09	0	2
Hand23	1.1	0.1	0.09	0	2	Hand23	1.1	0.1	0.09	0	2

Total statistics

# Q & A



Thank you for your attention...

