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

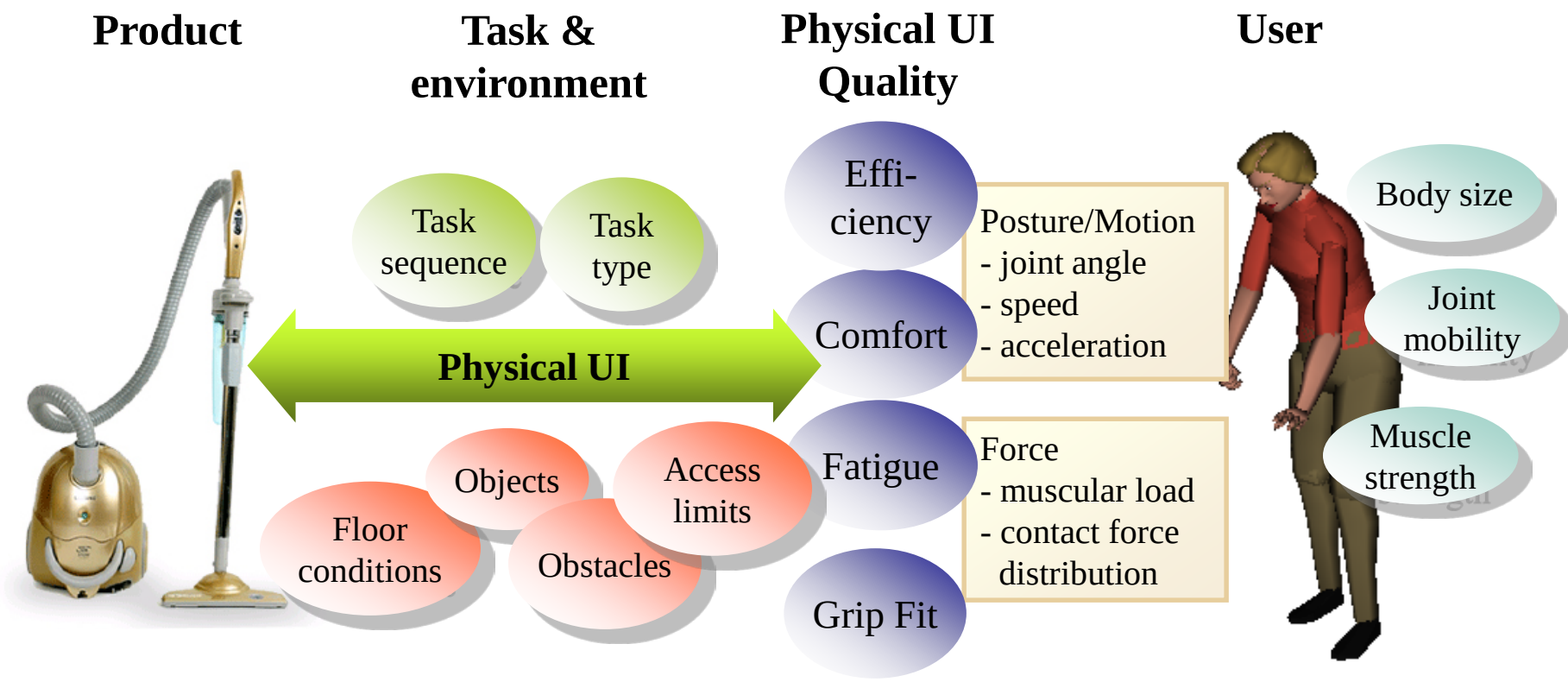
- Use of excessive hand force at work may cause upper-extremity musculoskeletal disorders (NIOSH, 1997).

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

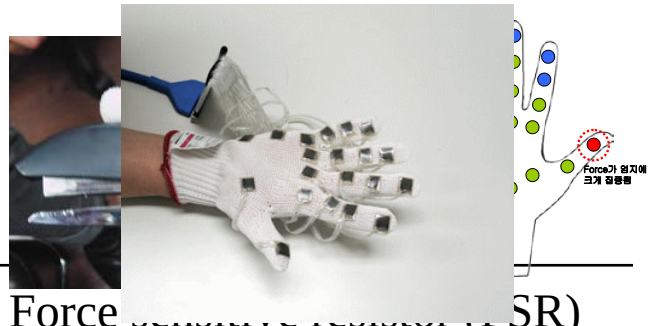
(Note) +++: strong evidence; ++: evidence, +: insufficient evidence

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	• Strain gauge	• Force sensitive resistor (FSR)
Measurement	• Composite forces applied on the handle	• Individual contact forces transferred to the surface of the product
Product evaluation	• Low applicability	• High applicability
Performance	• Accuracy: error < 0.0002 kgf • Stability & repeatability: CV < 1%	• Lack of comprehensive understanding

Objective of the Study

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

Evaluation Level	Criteria
(1) Sensor level (static condition)	(1) Stability
	(2) Repeatability
(2) System level (dynamic condition)	(3) Accuracy
	(4) Linearity

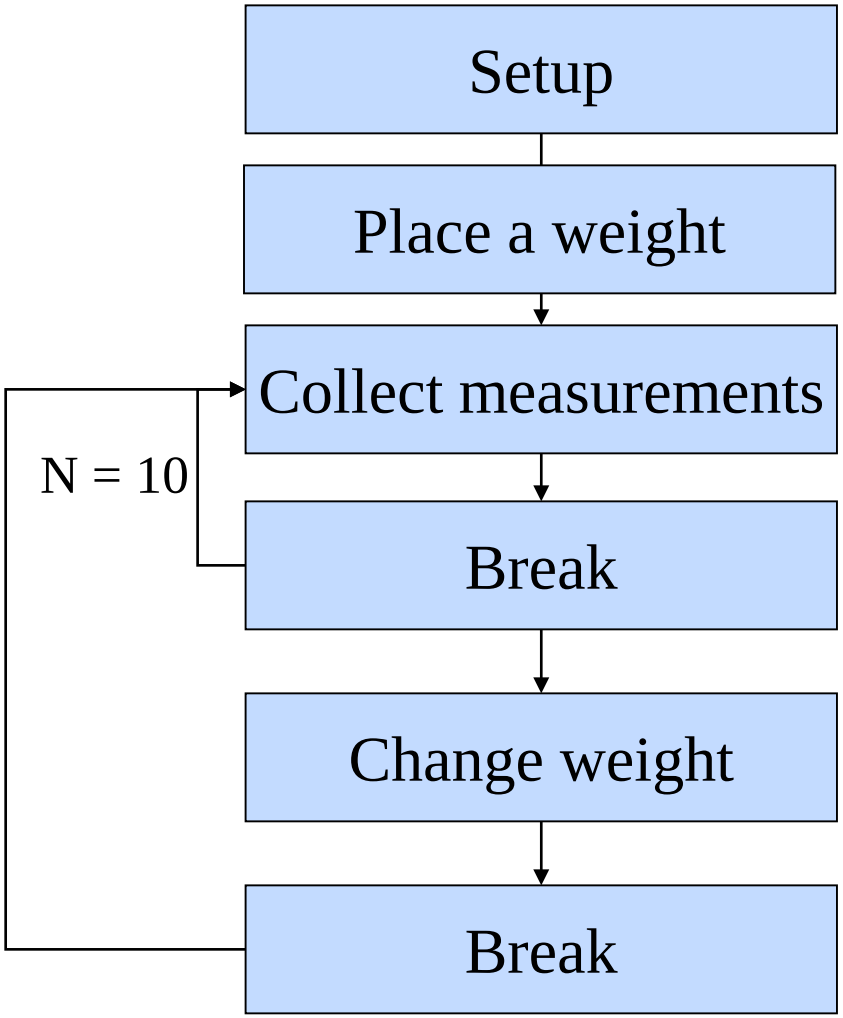
Method: Sensor Level Evaluation

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

Cube

FSR sensor

Sensor Level Evaluation Process



0.5 kg, 1 kg, and 2kg

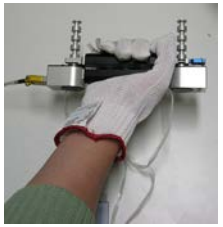
- Duration: 10 seconds
- Sampling rate: 10 Hz

30 seconds

120 seconds

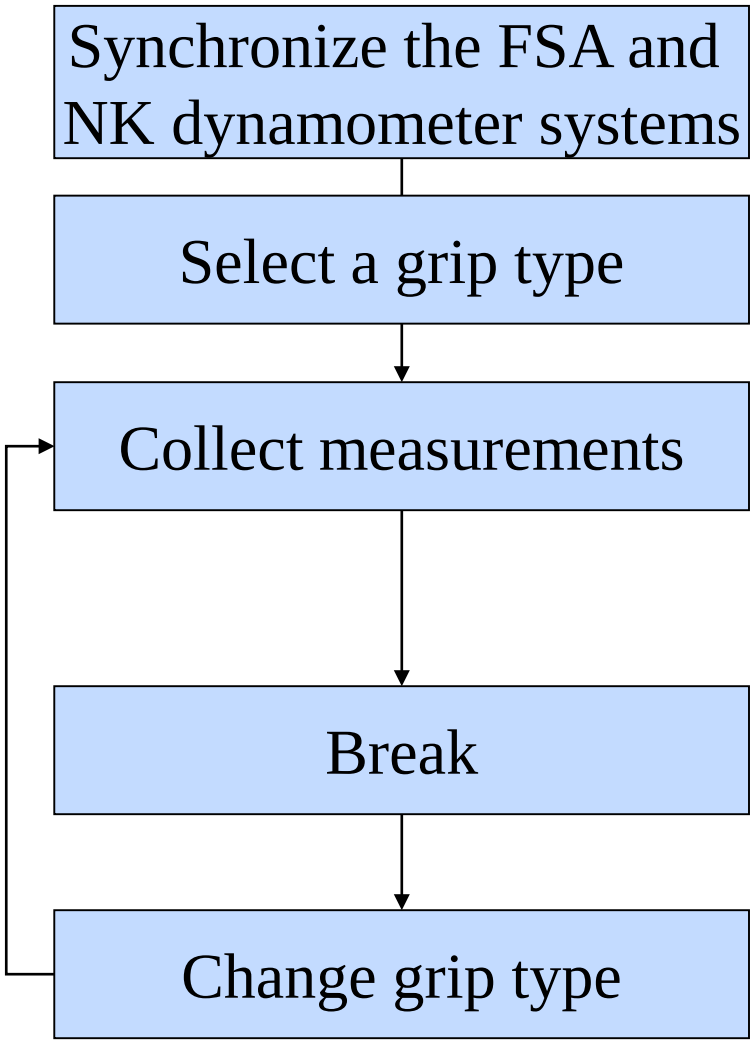
System Level Evaluation

- 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™ dynamometer (considered as a gold standard).

System Level Evaluation Process



The clocks of two computers synchronized by AboutTime™

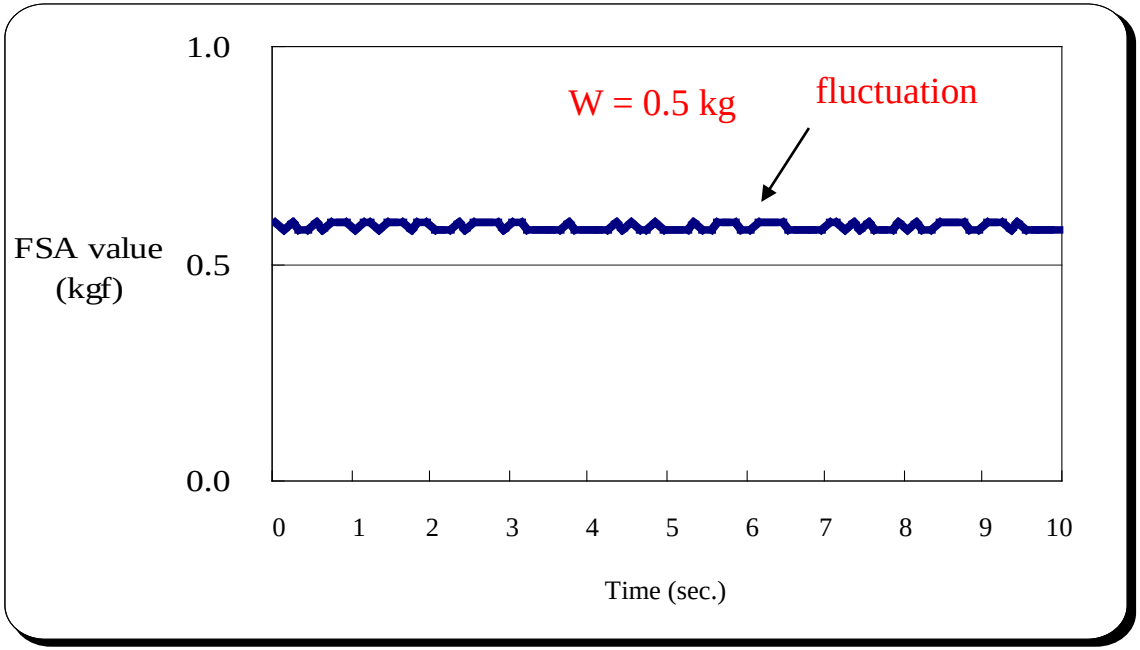
Press, Pinch, and Grip

- 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



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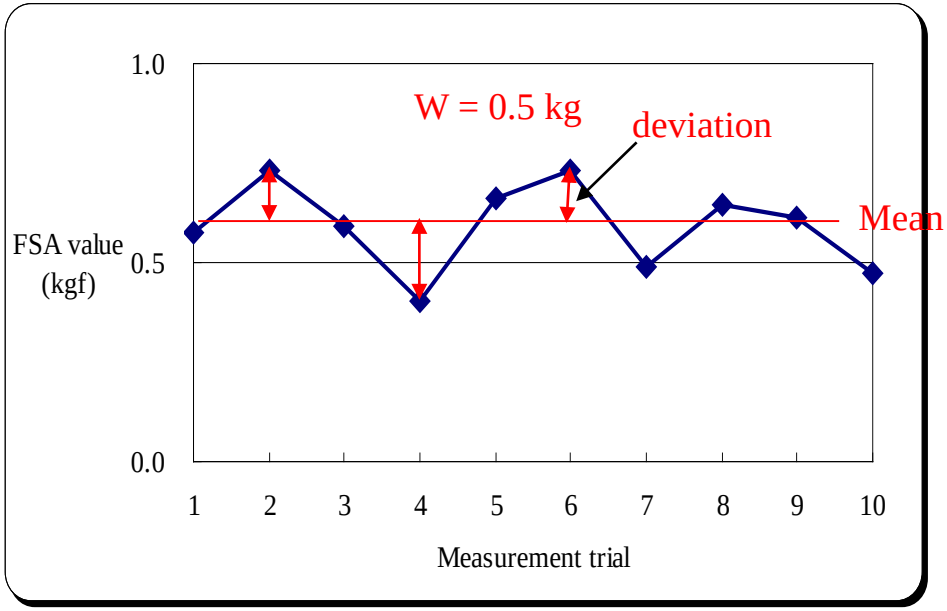

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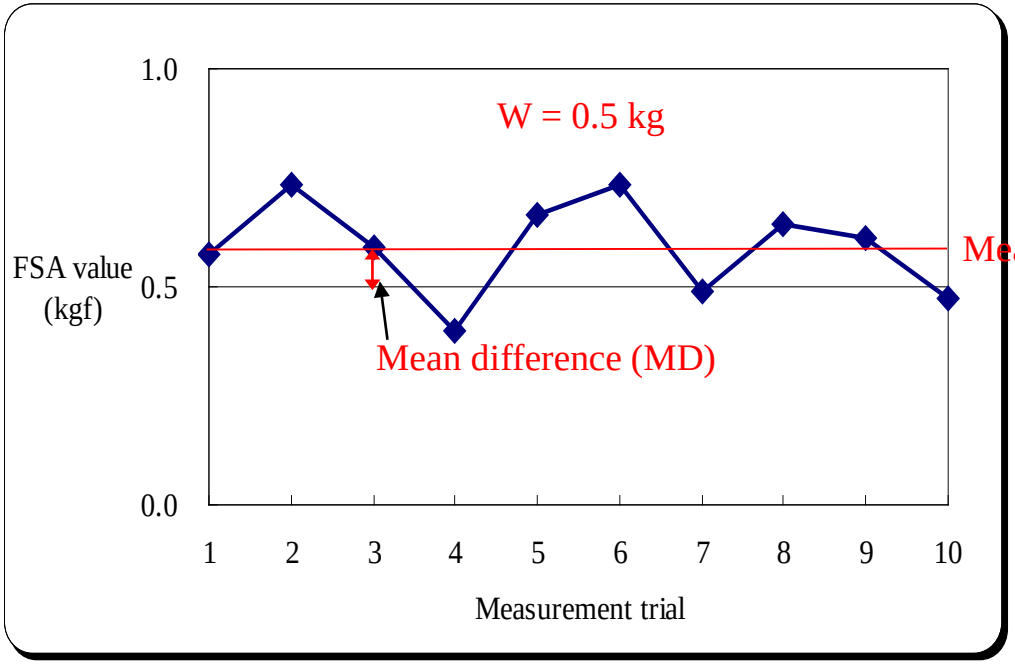

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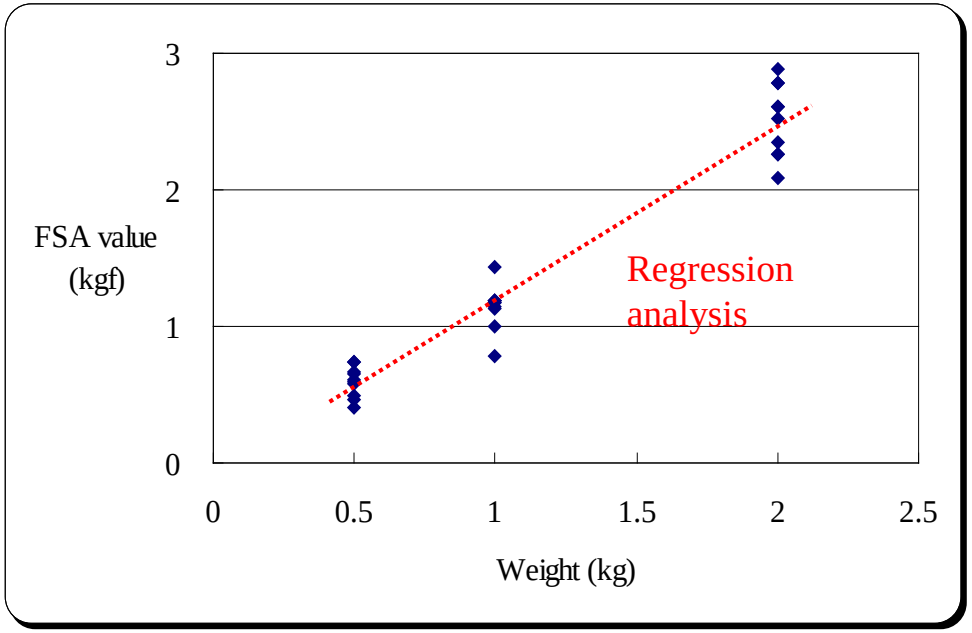
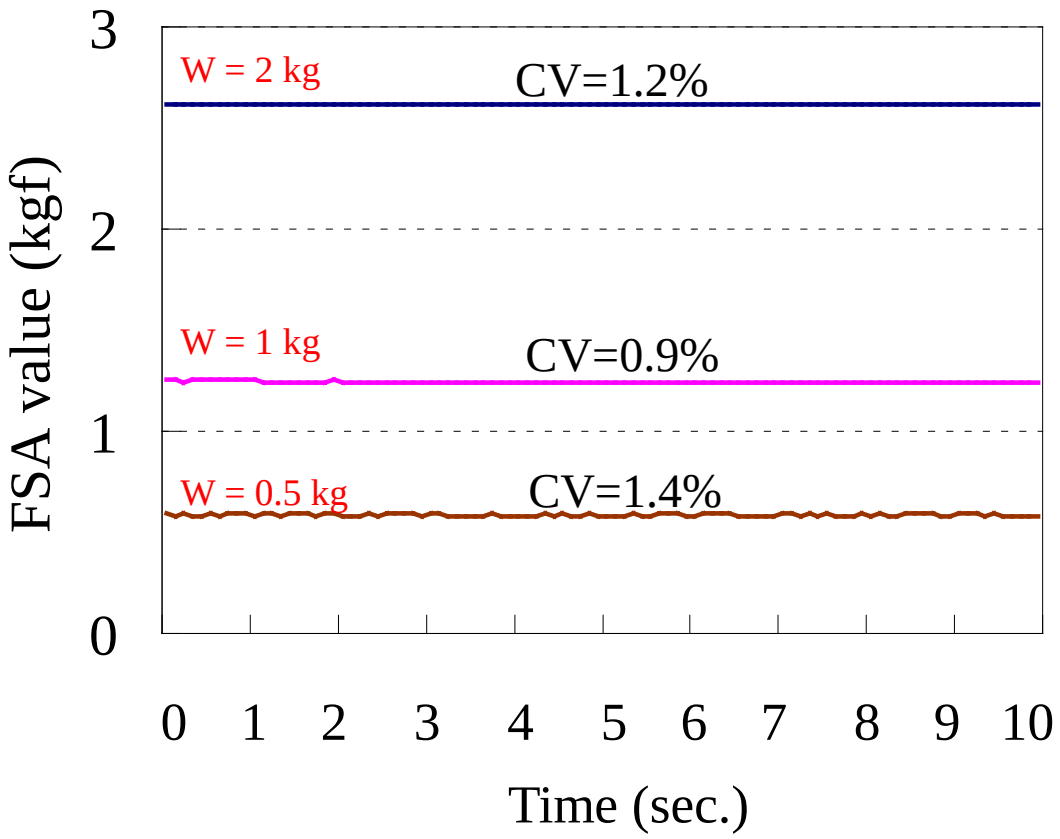


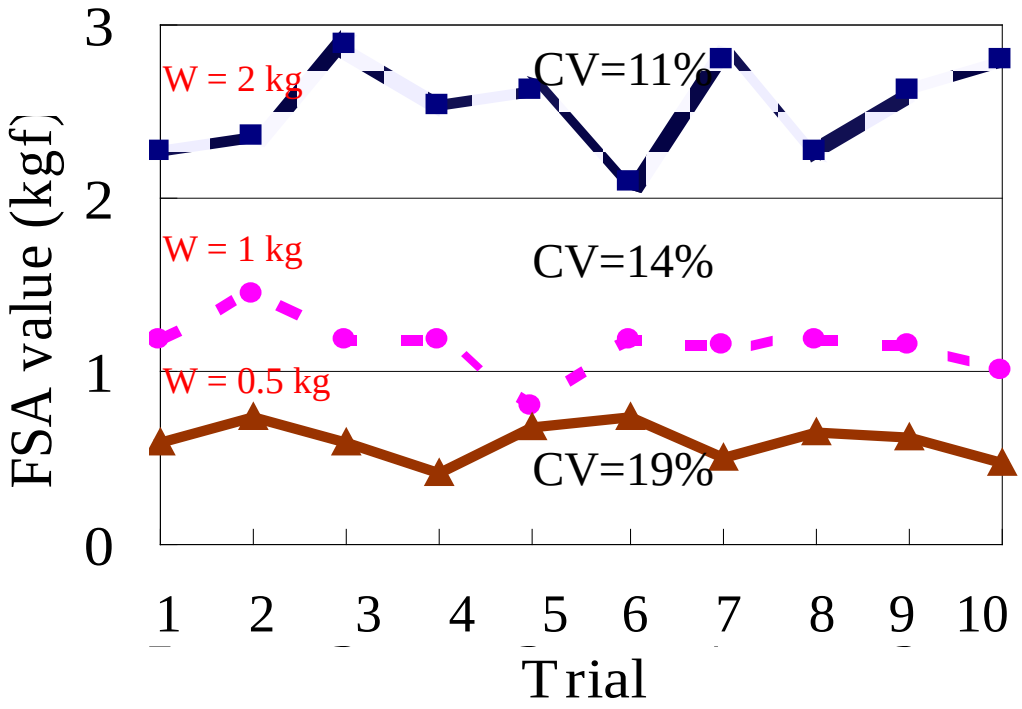
Sensor Level Result: Stability

- Fair stability: CV = 0.9 ~ 1.4%



Sensor Level Result: Repeatability

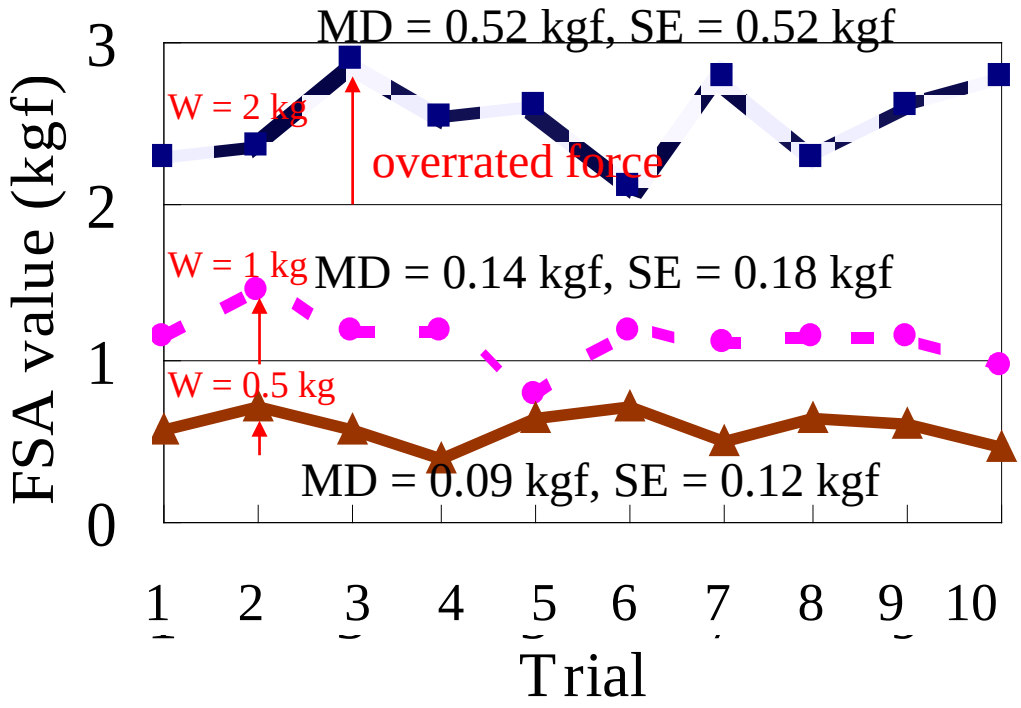
- Low repeatability: CV = 11 ~ 19%
- Repeatability decreases as weight decreases.



Sensor Level Result: Accuracy

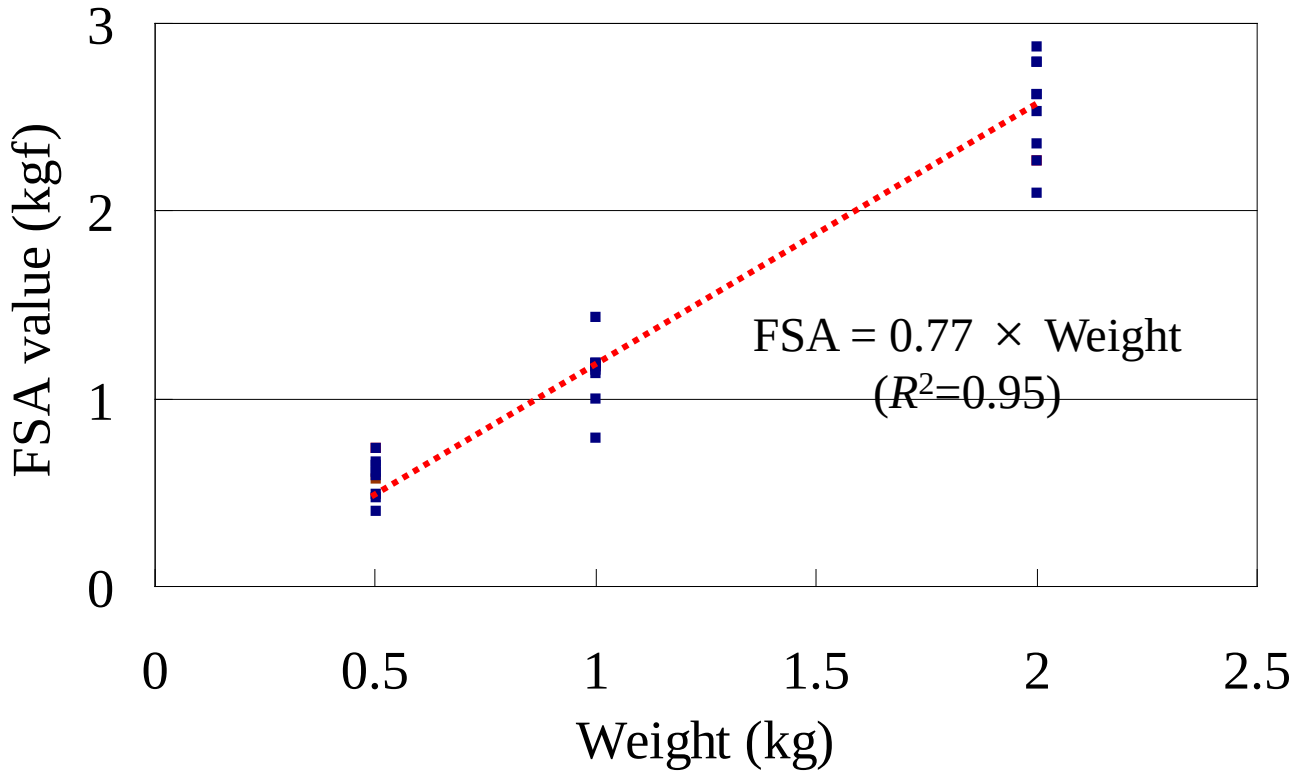
- Low accuracy: MD = 0.09 ~ 0.52 kgf, SE = 0.12 ~ 0.52 kgf
- MD and SE increase as weight increases.

  ⇒ Accuracy decreases as weight increases.
- Tendency to produce overrated values.



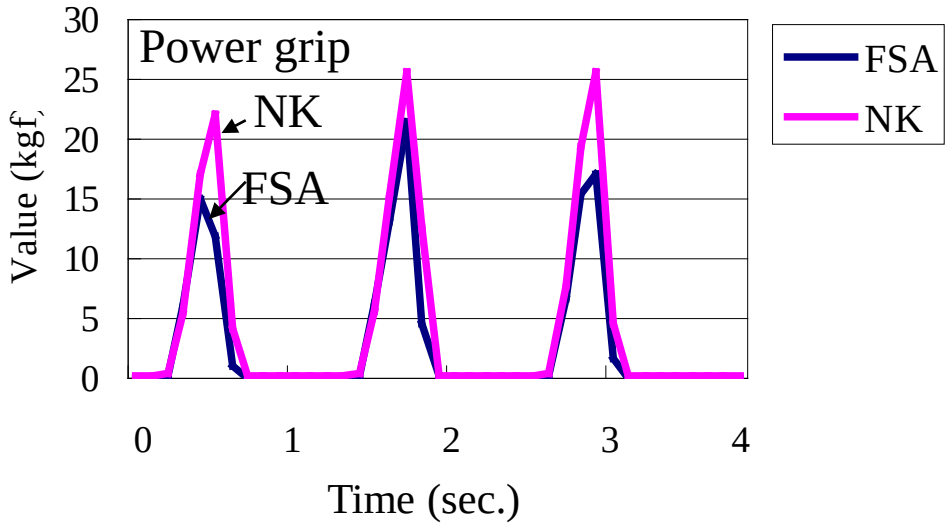
Sensor Level Result: Linearity

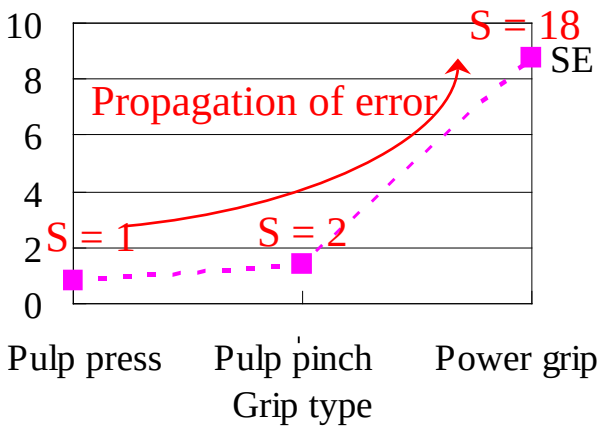
- High linearity: $R^2 = 0.95$



System Level Result: Accuracy

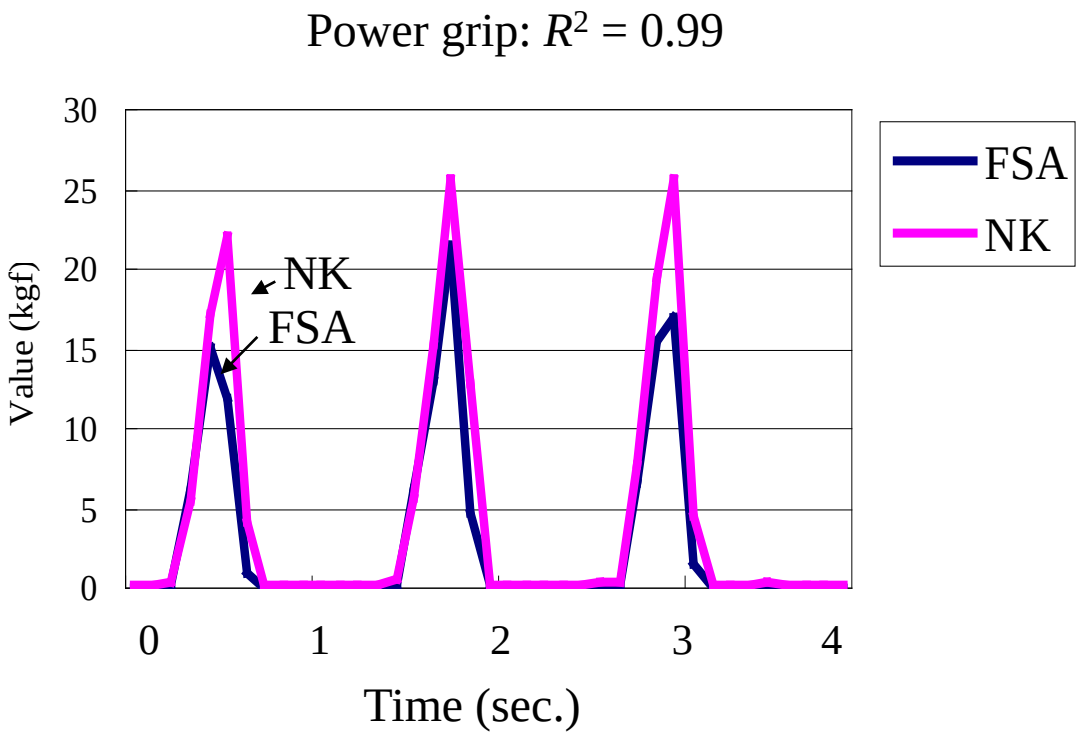
- Low accuracy: MDs = -0.09 ~ -1.49 kgf
- Negative MD values mean that the FSA system produce underrated forces than NK dynamometer.
- Propagation of error: SE at pulp press = 0.79, SE at pulp pinch = 1.4, SE at power grip = 8.73





System Level Result: Linearity

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



Discussion

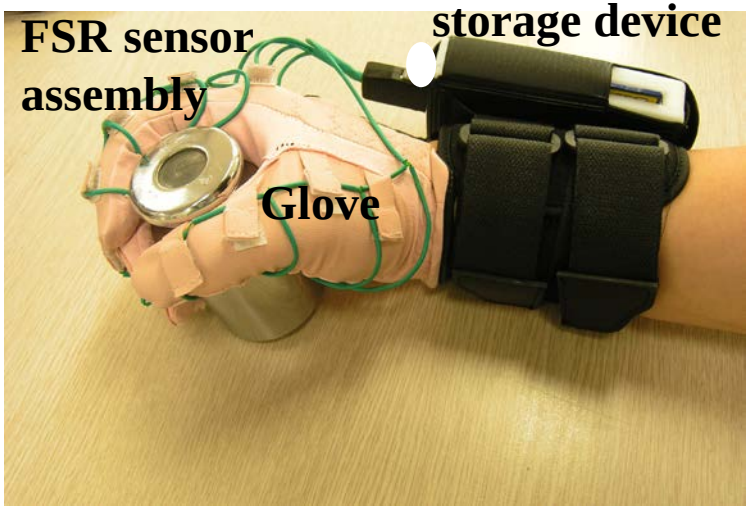
Criteria	Sensor level	System level
Stability	**Good** (CV = 0.9 ~ 1.4%)	-
Repeatability	**Satisfactory** (CV = 11 ~ 19%)	-
Accuracy	**Satisfactory** (MD = 0.09 ~ 0.52 kgf)	**Satisfactory** (MD = -0.09 ~ -1.49 kgf)
Linearity	**Good** (R^2 = 0.95)	**Good** (R^2 = 0.82 ~ 0.99)

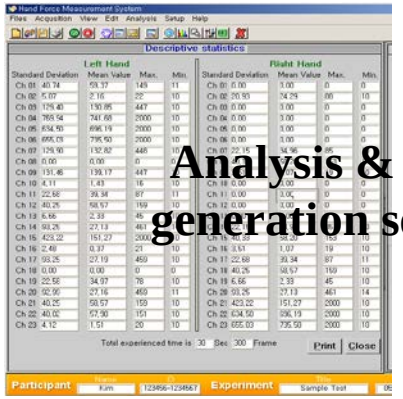
Discussion

- 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.

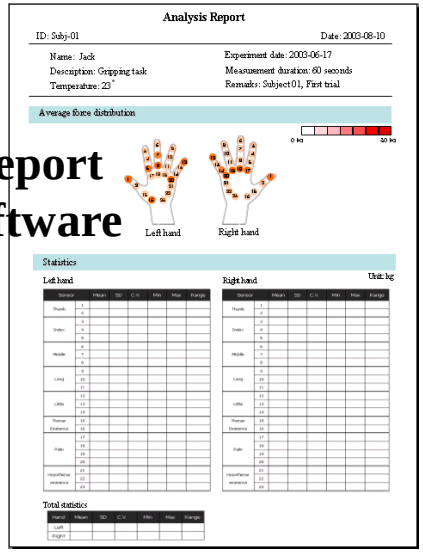
Follow-up Study

- 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





Analysis & report generation software



Q & A