An Analysis of Natural Motion for Product Design: Refrigerator Half-Guard Installation Part Design

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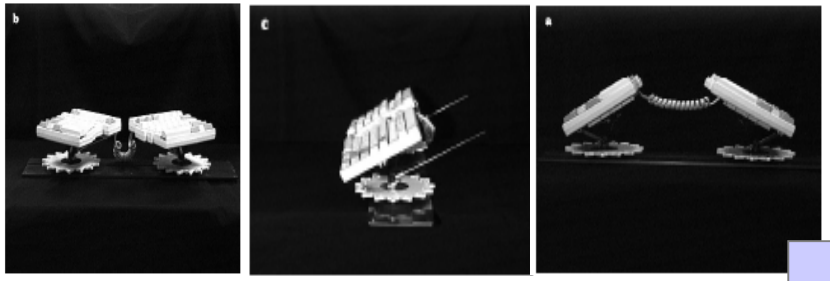
AGENDA

- Motivation
- Objectives of the Study
- Natural Motion Analysis & Novel Design Development
- Design Evaluation
- Discussion

Posture & Motion Analysis

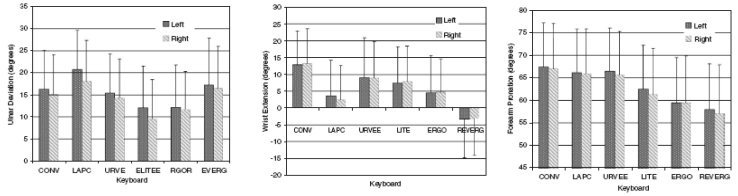
- Postures and motions of users taken to operate a product have been analyzed for ergonomic product design

Various design configurations



	Keyboard configuration					
	CONV	LAP	CURVE	ELITE	ERGO	REVERGO
Split angle (deg.)	0	0	6	12	12	12
Gable angle (deg.)	0	0	0	8	14°	14
Slope (deg.)	0	0	0	0	0	−7
Height (mm)[a]	30	35	20	41	36	49
Horizontal (mm)[b]	67	166	87	132	151	149
D to K (mm)[c]	95	94	106	144	138	138

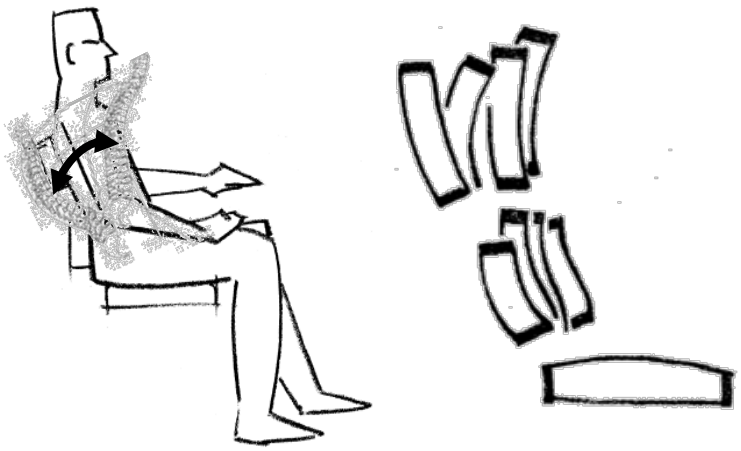
Posture analysis



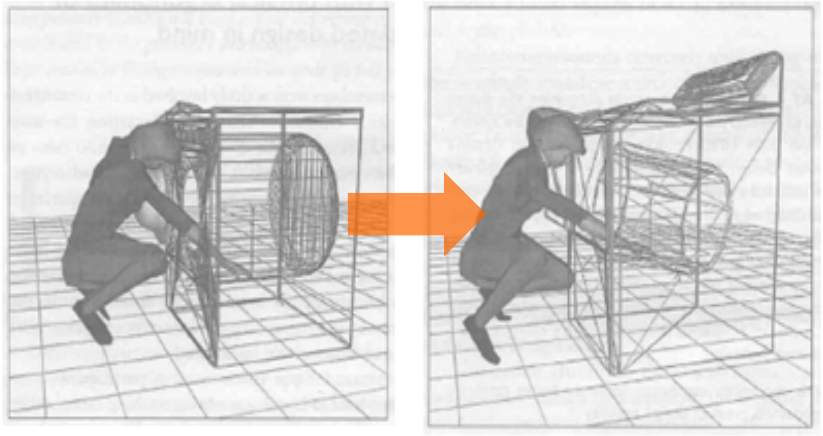
Nelson et al. (2000), Rempel et al. (2007)

Ergonomic Design for Natural Posture & Motion

- Novel ergonomic designs have been developed by considering natural postures and motions that users prefer



Adjustable seatback
(Ailie et al., 1999)



Tilted Drum Washing Machine
(Nyberg and Kempic, 2006)

Limitation of Natural Motion-Based Product Design

Have proposed novel designs, but…

- **Objective, quantitative analysis?**

  ⇒ How to objectively identify a natural motion that the user prefer to use a product

- **Systematic application to design process?**

  ⇒ How to apply an identified natural motion to develop a product design

- **Validity evaluation of a new product design?**

  ⇒ Verify if a natural motion-based product design is effective

Objectives of the Study

Examine the effectiveness of natural motion analysis for ergonomic product design

Measurement & Analysis

- Measure and analyze motions to use a product while users feel their motions are comfortable and natural

Application to product design

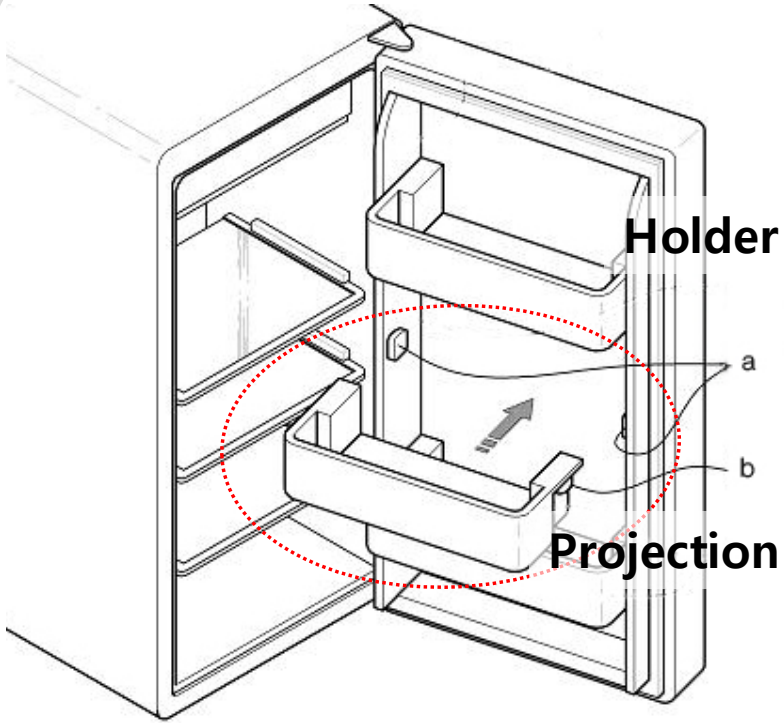
- Apply natural motion analysis results to develop novel designs

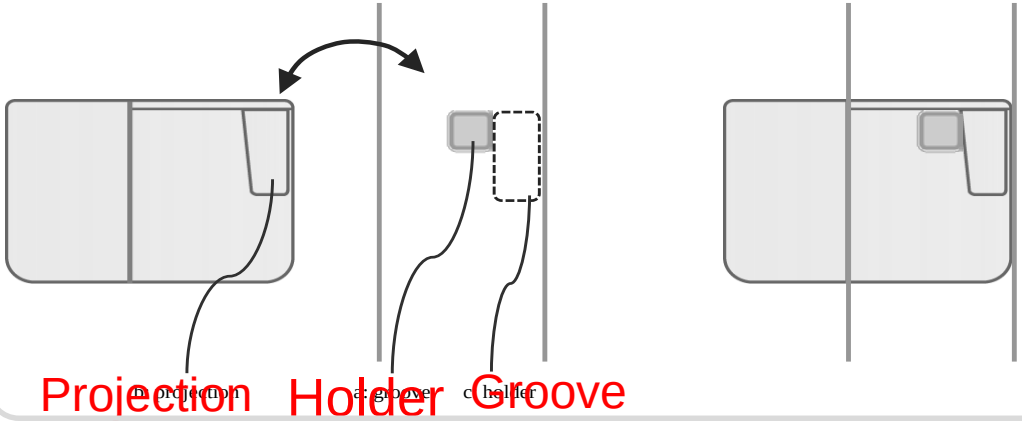
Validation of natural motion-based design

- Compare novel designs with existing designs in terms of (1) similarity between natural motions and product-use motions and (2) subjective satisfaction

Case Study

- The installation part of a refrigerator half-guard was selected for a case study of natural motion analysis





Half guard installation motion

Natural Motion Analysis & Design Development

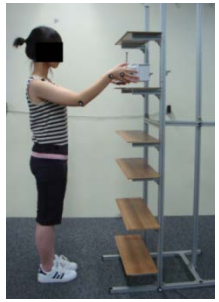
S1 Use context analysis

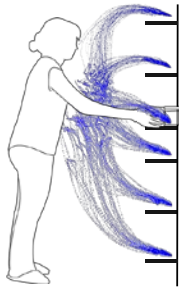
S2 Design analysis

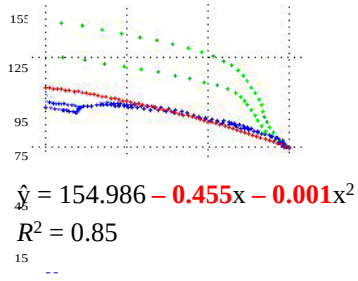
S3 Natural motion measurement

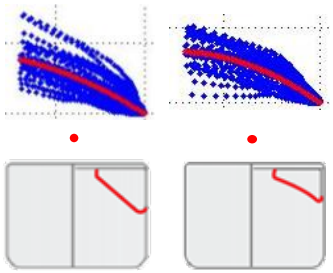
S4 Natural motion analysis

S5 Design development







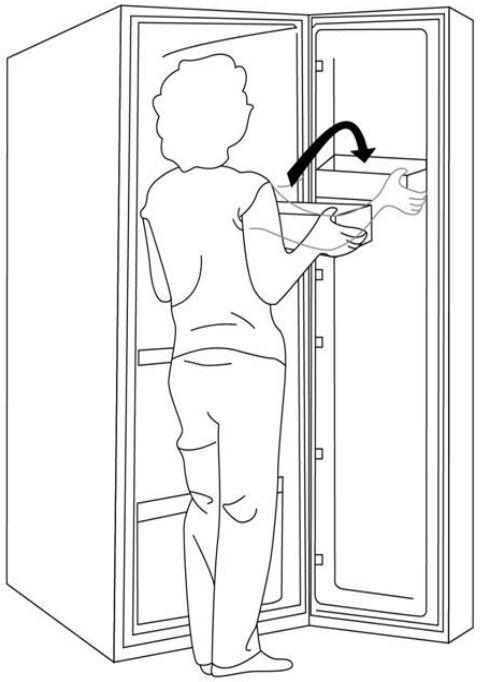


S1. Use Context Analysis

- Usability problems of the half-guard identified at FGI (20 homemakers of 30s to 50s)
  - ✓ Use of high forces of the hands
  - ✓ Jerky motions of the upper limbs
  - ✓ Unnatural (not curved) motions of the hands
  - ✓ Bent postures of the wrists
  - ✓ Repeated trials when assembling/disassembling the half guard to/from the door panel

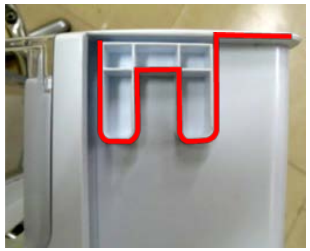
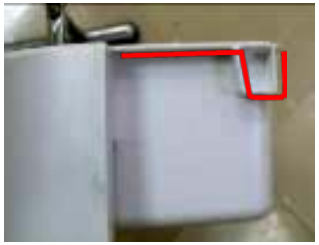
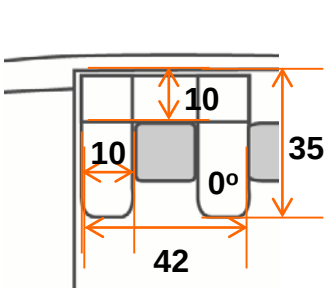
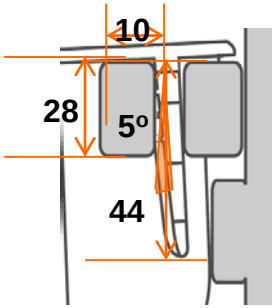
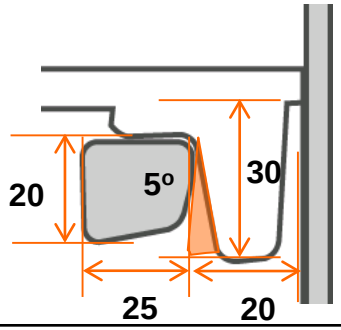
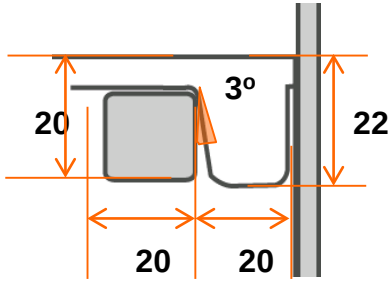
- Frequency of the half-guard assembly/disassembly is low, but improvement of usability, product quality, ease of assembly in manufacturing

1. **Improper design** of the half-guard installation part !!
2. **Absence of a proper cue and feedback** to assist the assembling task !!



S2. Design Analysis

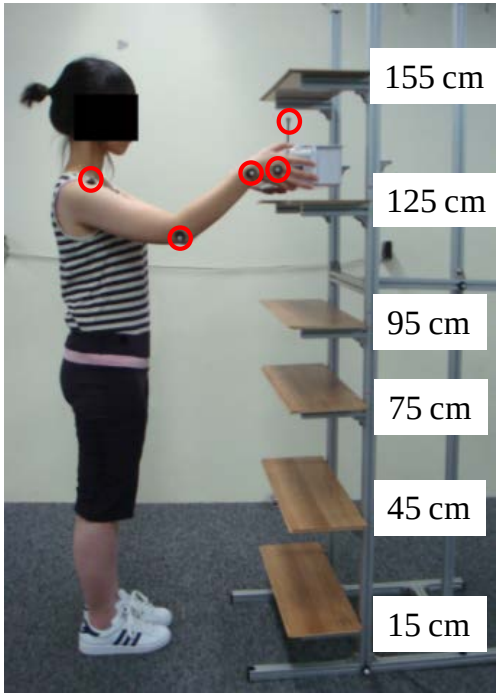
- The design variables of the half-guard installation part were analyzed and the design features of 10 competitive product models were benchmarked

	Half-guard design			
Design Var.	T1	T2	T3	T4
	Gripper	Wedge: triangular	Wedge: trapezoid	Wedge: rectangular
Projection - Shape				
Holder – Dimensions				

S3. Natural Motion Measurement

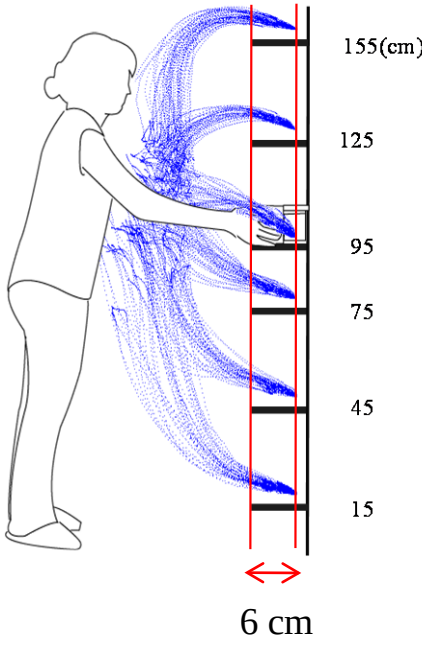
- **Participants**: 18 homemakers (age: 44 ± 9; stature: 157.4 ± 5.3 cm, 148.7 ~ 173.5 cm)
- **Task**: Place a half-guard held by the hands in front of the chest on a designated shelf using a natural motion and bring it back to the initial position
- **Apparatus**: 6 motion capture cameras (Hawk-I, Motion Analysis Co., U.S.A.)

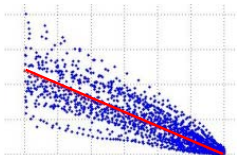
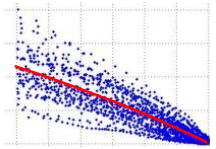
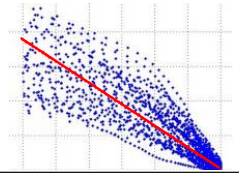
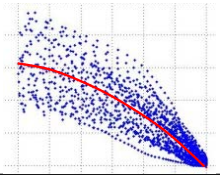
Markers (Ø = 1.2 cm)



S4. Natural Motion Analysis

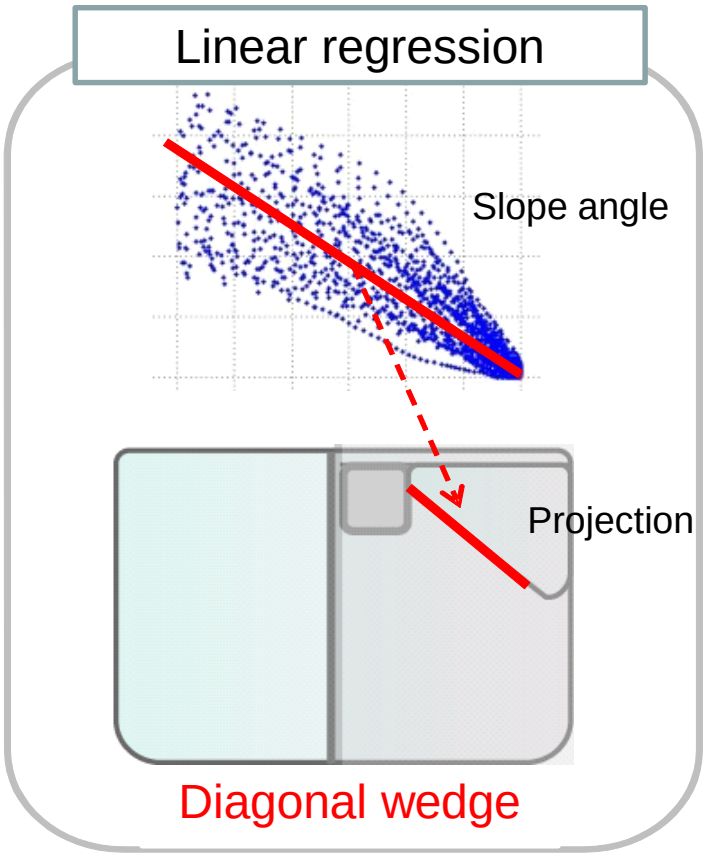
- Identified representative natural motion trajectories for the installation/uninstallation of the half-guard at 6 different heights by regression analysis
- Established linear and quadratic regression models

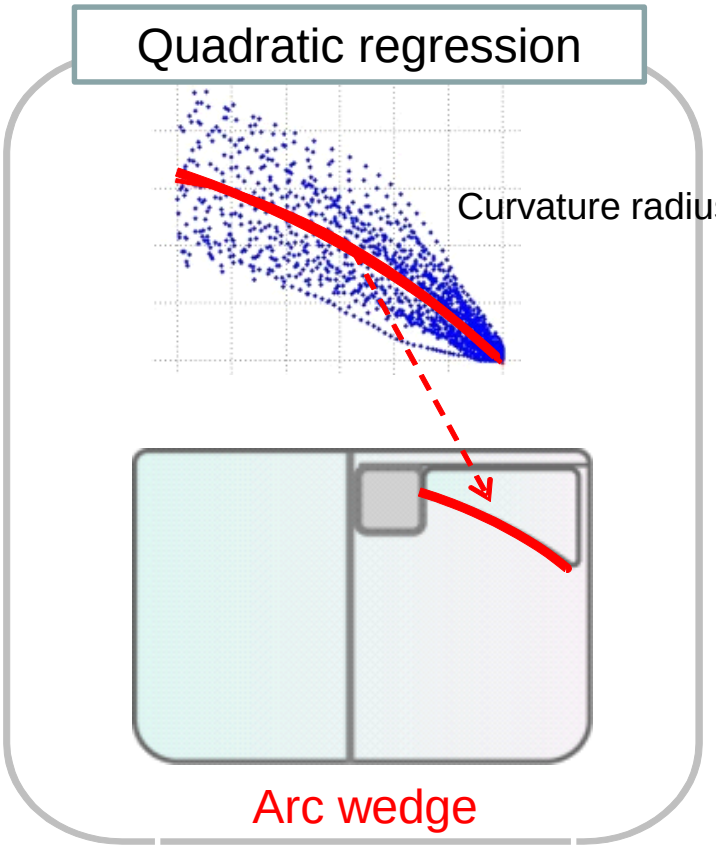


Guard installation height (cm)	Linear regression		Quadratic regression	
	Trajectory	Formula	Trajectory	Formula
155		$\hat{y} = 155.002 - 0.397x$ $R^2 = 0.85$		$\hat{y} = 154.986 - 0.455x - 0.001x^2$ $R^2 = 0.85$
125		$\hat{y} = 125.020 - 0.625x$ $R^2 = 0.83$		$\hat{y} = 124.939 - 0.918x - 0.006x^2$ $R^2 = 0.85$
⋮	⋮		⋮	⋮

S5. Design Development

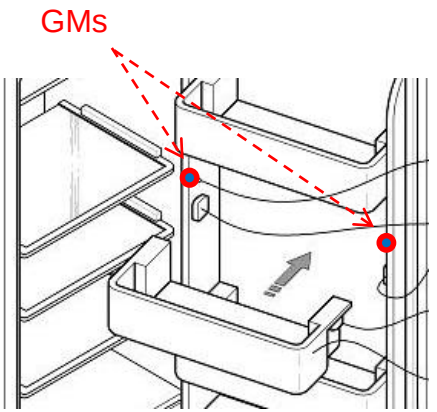
- Developed two novel designs of the installation part by considering the characteristics of the representative motion trajectories identified

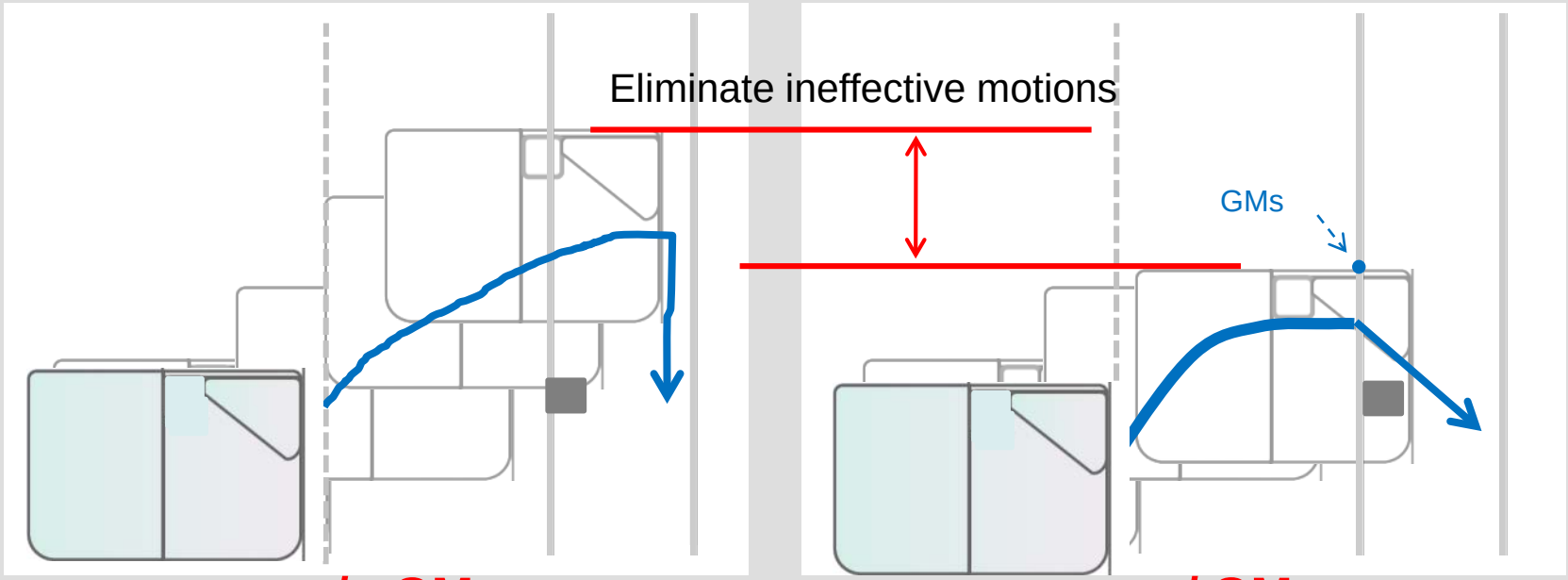




S5. Design Development: Guide Marker

- Provided guide makers (GMs) on the indoor panel
  - ✓ Reduce ineffective motions when assembling the half-guard to the inner door panel due to absence of a visual cue
  - ✓ Help the user position the half-guard more effectively on the door panel and slide it into the groove for installation

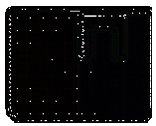
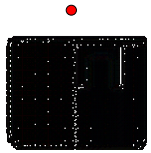
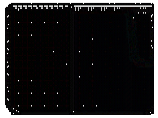
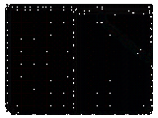
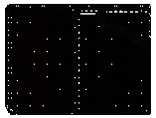




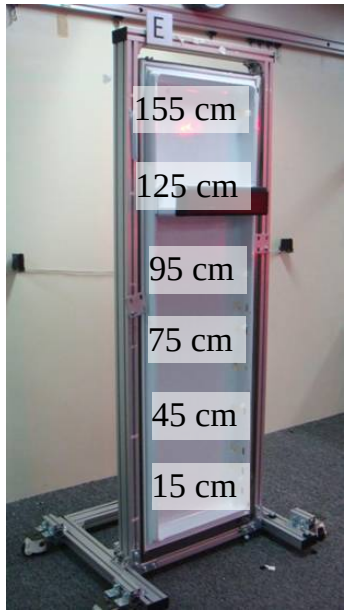
Design Evaluation

- Participants: 18 homemakers (the same participant group)
- Two-factor within-subject design

Half-guard design (5 levels)

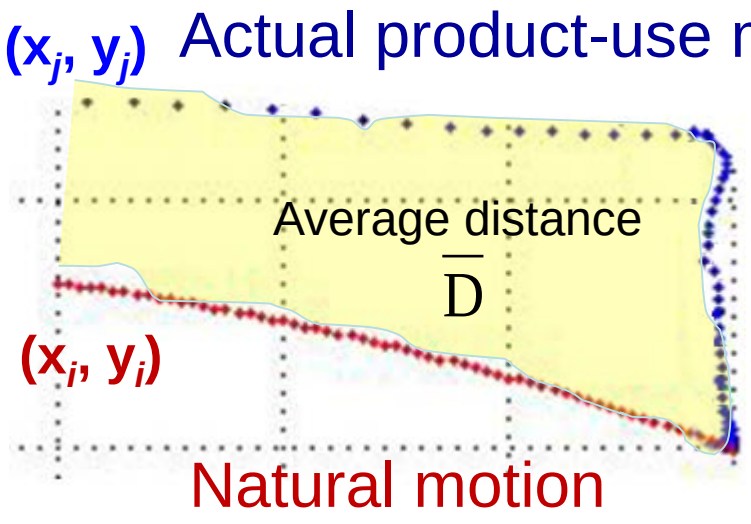
Gripper w/o GMs	Gripper w/ GMs	Rectangular wedge w/ GMs	Diagonal wedge w/ GMs	Arc wedge w/ GMs
				

Installation height (6 levels)



Evaluation Measures

No.	Measure	Metric
1	Motion similarity	Average distance between actual product-use and natural motion trajectories (unit: cm)
2	Ease of installation/uninstallation	7-point scale (1: very dissatisfied; 4: neutral; 7: very satisfied)



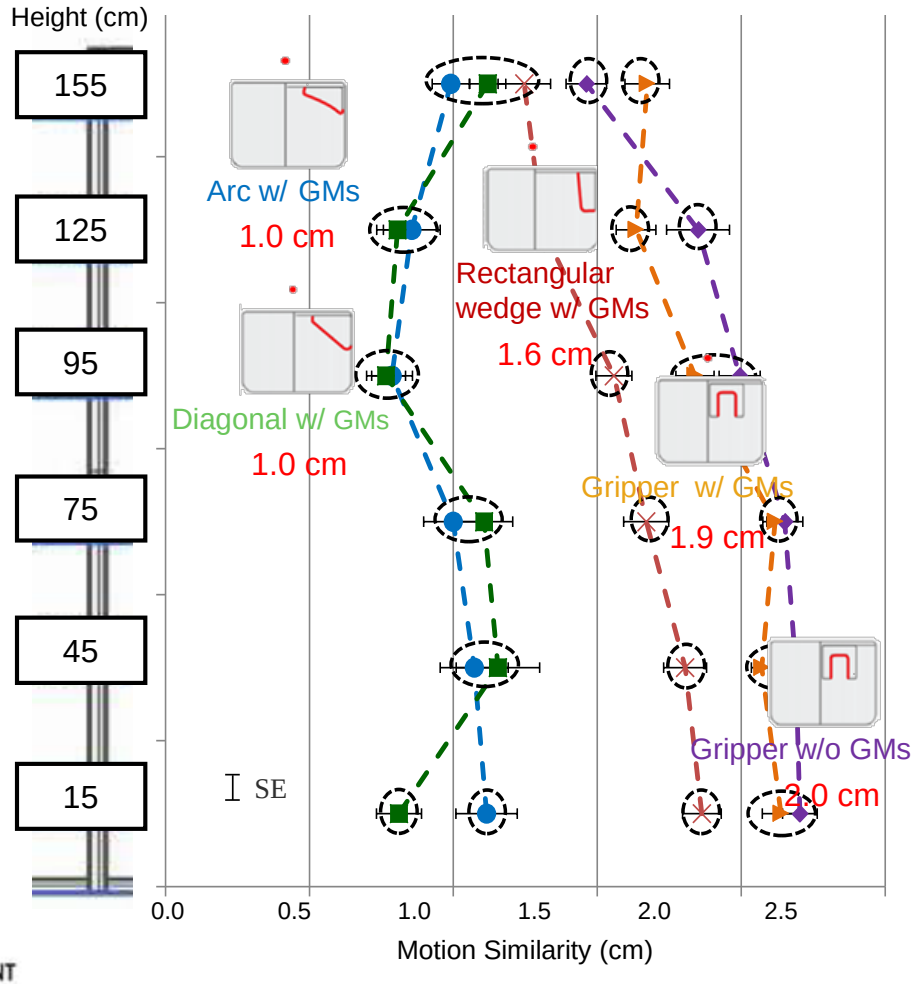
$$D_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

$$D_i = \min_j (D_{ij})$$

$$\overline{D} = \frac{\sum_{i=1}^{n} D_i}{n}$$

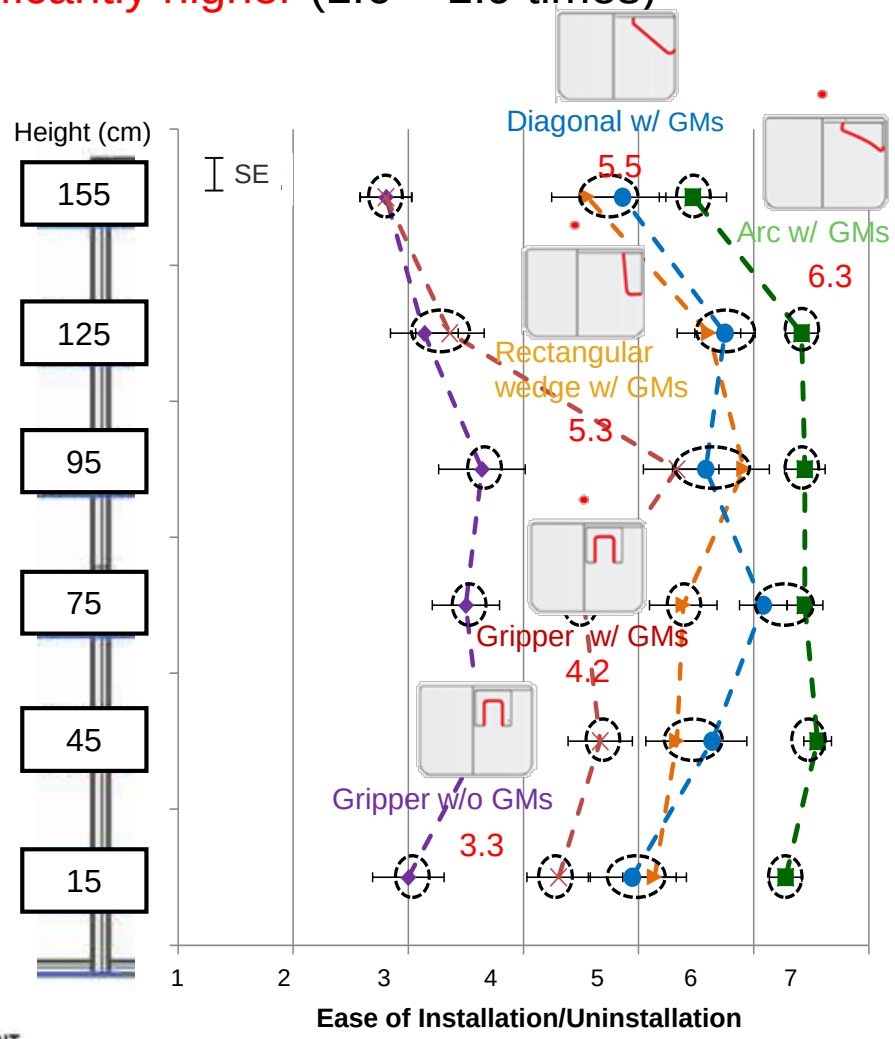
Results: Motion Similarity

- The actual motions of diagonal & arc wedges w/ GMs were significantly closer (1.0 cm) to corresponding natural motions



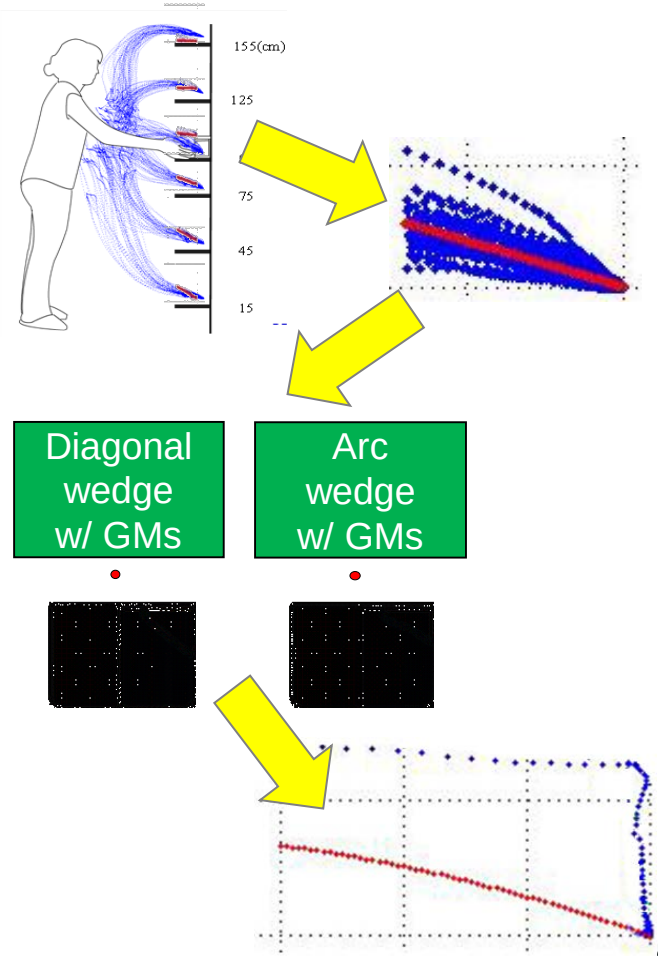
Ease of Installation/Uninstallation

- The subjective score of arc & diagonal wedges w/ GMs and rectangular wedge w/ GMs was significantly higher (1.6 ~ 1.9 times)



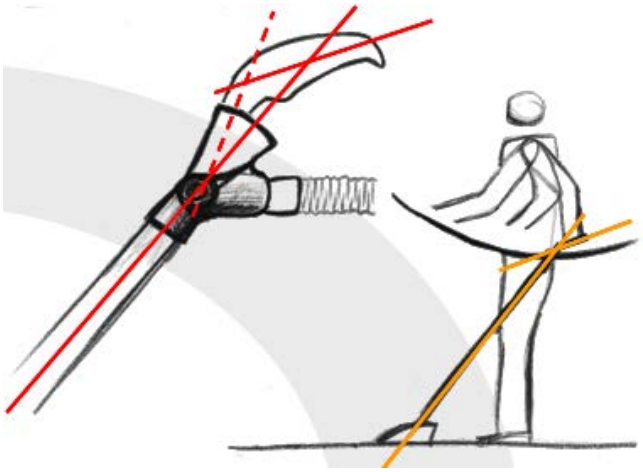
Discussion

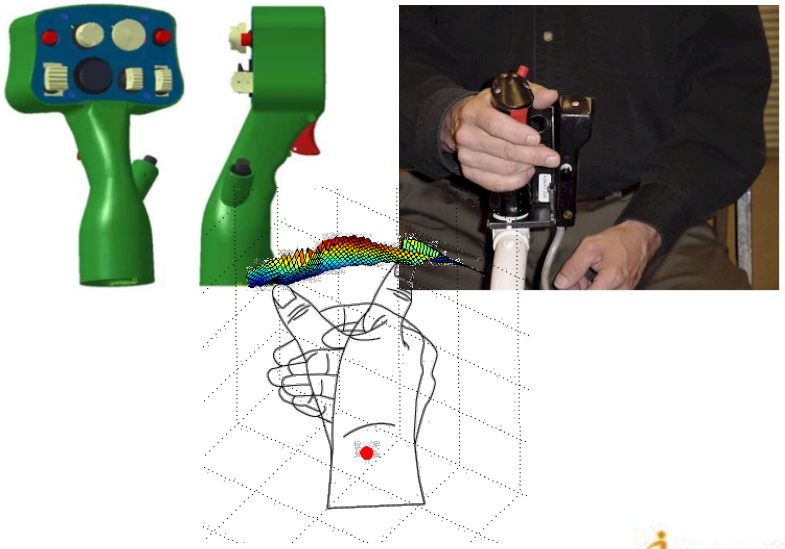
- Examined the **effectiveness of natural motion analysis** for **development of an ergonomic product design**
  - ✓ Objective measurement of natural motion using a motion capturing system
  - ✓ Curve fitting of a natural motion by regression analysis
  - ✓ Application of identified natural motions to development of novel product designs
  - ✓ Evaluation of product designs based on natural motion analysis in terms of motion similarity and subjective satisfaction



Discussion (cont'd)

- Proposed novel, effective designs for the installation part of half-guard
  - ✓ Diagonal & arc wedges ⇒ facilitating actual product-use motions to become similar to corresponding natural motions
  - ✓ Guide marker ⇒ eliminating ineffective motions in product use
- Explore the effectiveness of natural motion analysis in various applications





Q & A