

*Quantifying Coordination and Its
Application to Evaluating 6 DOF
Control Devices*

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Quantifying 6 DOF performance

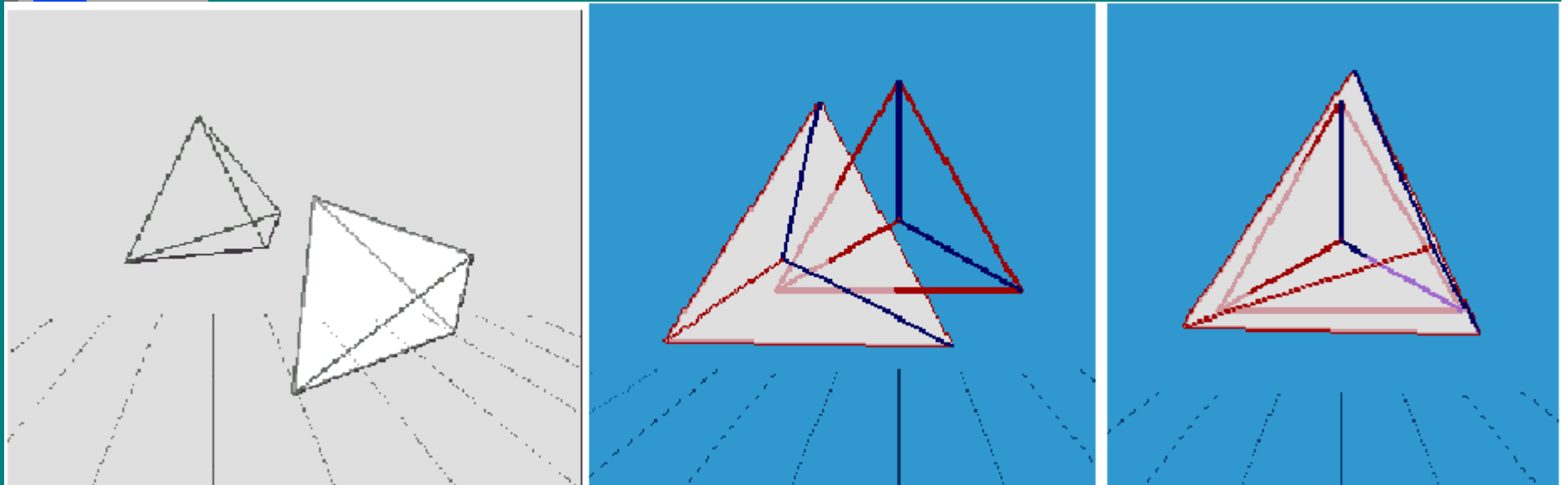
- *A variety of 6 DOF control devices*
- *Which is better?*
- *Measures: time, accuracy, and ?*
- *Coordination: can all DOF be used effectively?*

Simultaneous time-on-target (TOT)

- *Ellson (1947)*
 - *Comparing $TOT_b (= TOT_x TOT_y)$ with Simultaneous TOT (TOTs)*
 - *independent: $TOTs = TOT_b$*
 - *discoordinated: $TOTs < TOT_b$*
 - *coordinated: $TOTs > TOT_b$*
 - *In a Pedestal Sight Manipulation Test (PSMT), $TOTs < TOT_b$*
- *Gardner (1950): $TOTs = TOT_b$*

TOT in a 6DOF tracking experiment

- *6 DOF tracking in a virtual environment*

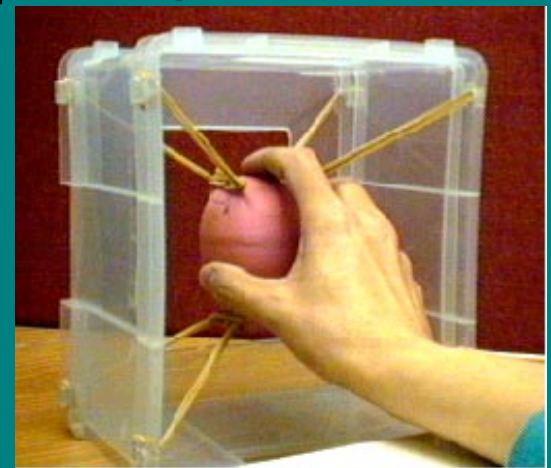


6 DOF tracking experiment

- *Two 6DOF controllers*
- *13 subjects each group*
- *5 tests, 4 trials per test
total of 1 hour experiment*



Spaceball



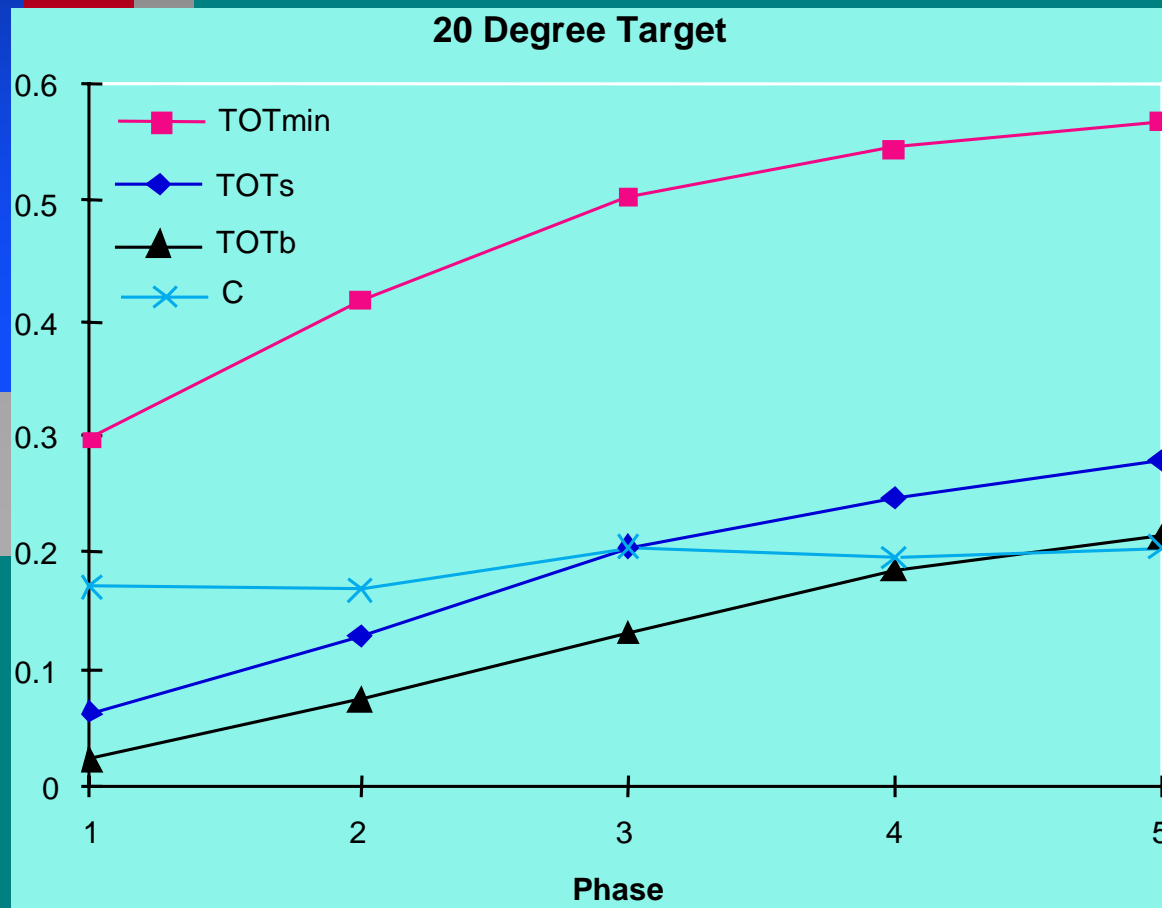
EGG

(Elastic General purpose Grip)

TOT (%) in 6DOF tracking

- $TOT_b = TOT_x \cdot TOT_y \cdot TOT_z \cdot TOT_{rx} \cdot TOT_{ry} \cdot TOT_{rz}$
- $TOT_{min} = \min (TOT_x, TOT_y, TOT_z, TOT_{rx}, TOT_{ry}, TOT_{rz})$
- $TOT_s = 6 \text{ DOF simultaneously on target}$
- $C = (TOT_s - TOT_b) / (TOT_{min} - TOT_b)$
 - $C < 0$: $TOT_s < TOT_b$, worse than chance, DISCOORDINATED
 - $C = 0$: $TOT_s = TOT_b$, no better than chance, UNCOORDINATED
 - $C = 1$: $TOT_b = TOT_{min}$, PERFECT coordination
 - $0 < C < 1$: $TOT_b < TOT_s < TOT_{min}$, COORDINATED

6 DOF tracking TOT results



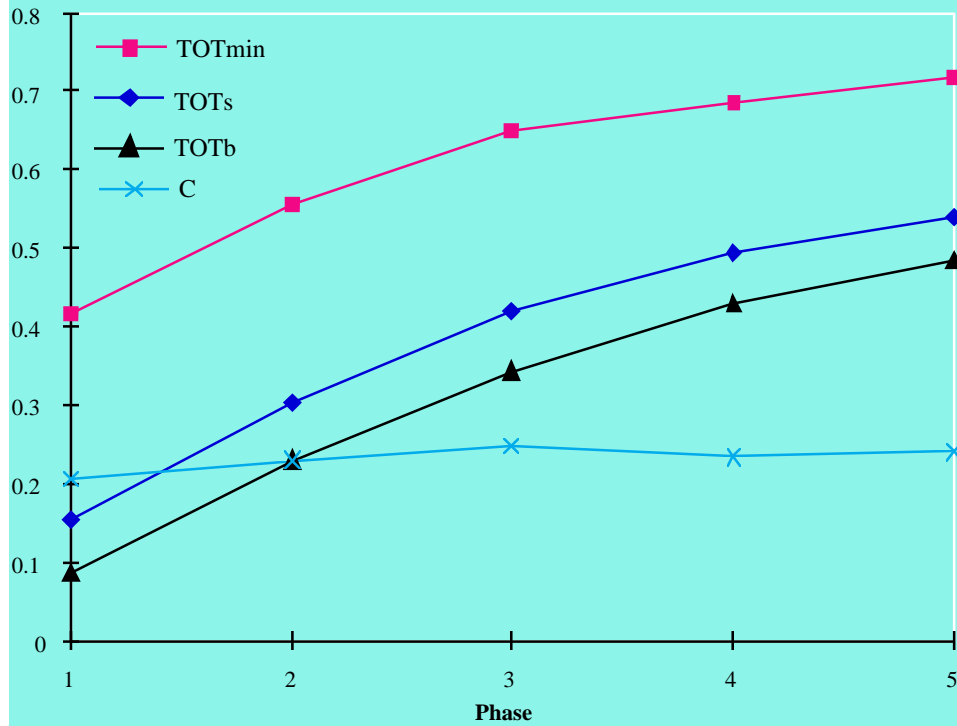
■ Contrary to the results of Ellson (1947) and Gardner(1950)

■ $C > 0$

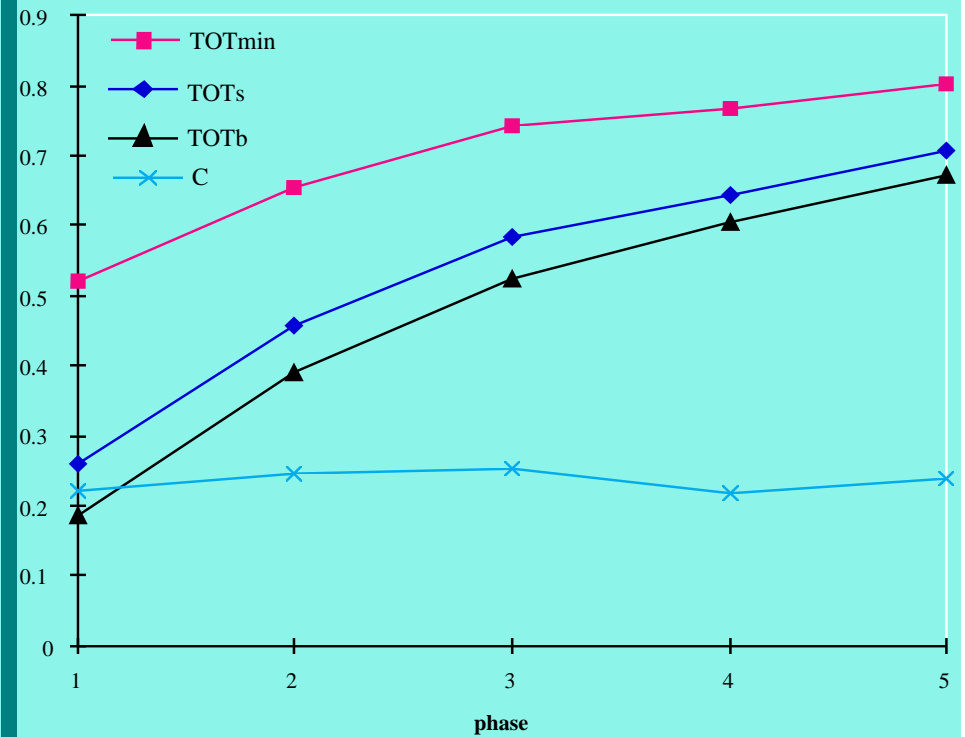
■ $TOTs > TOTb$

Results with different target sizes

30 Degree Target

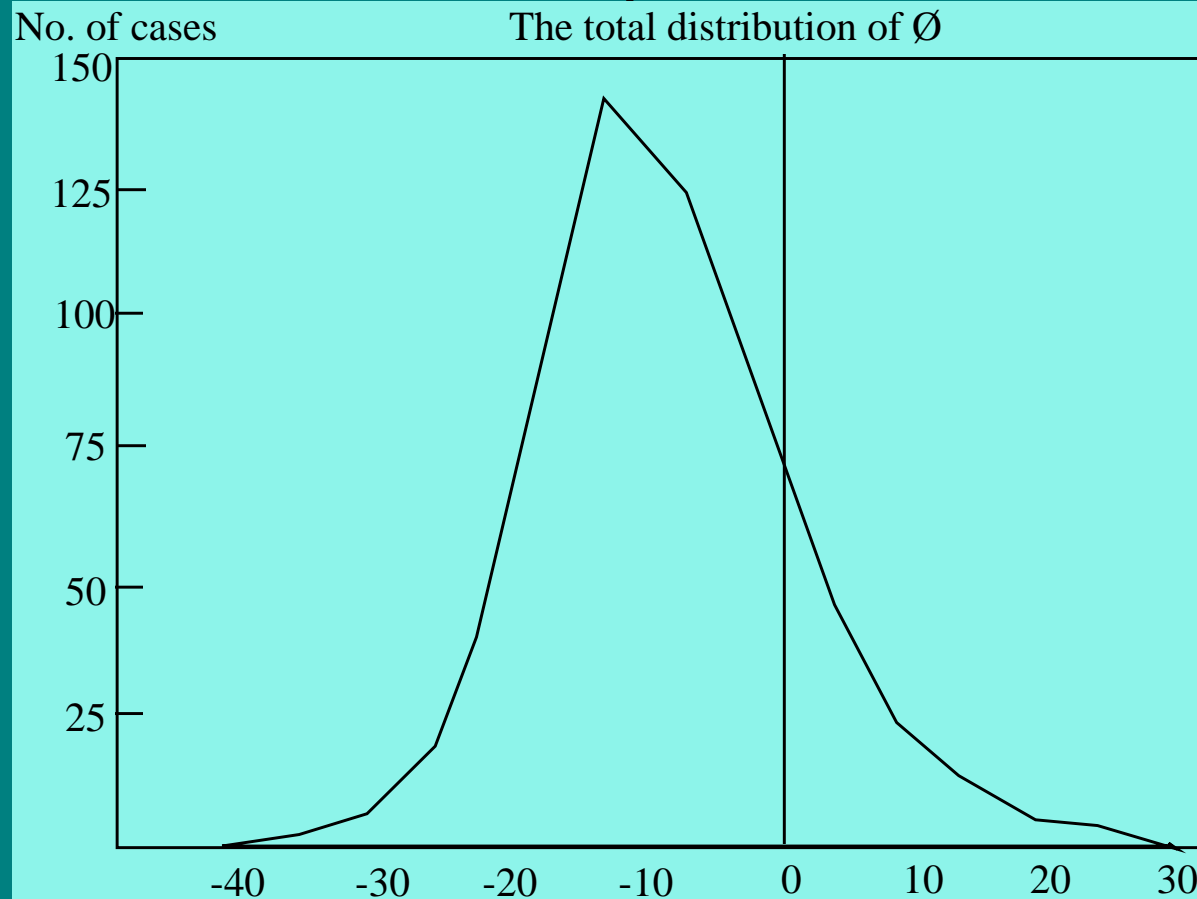


40 Degree Target

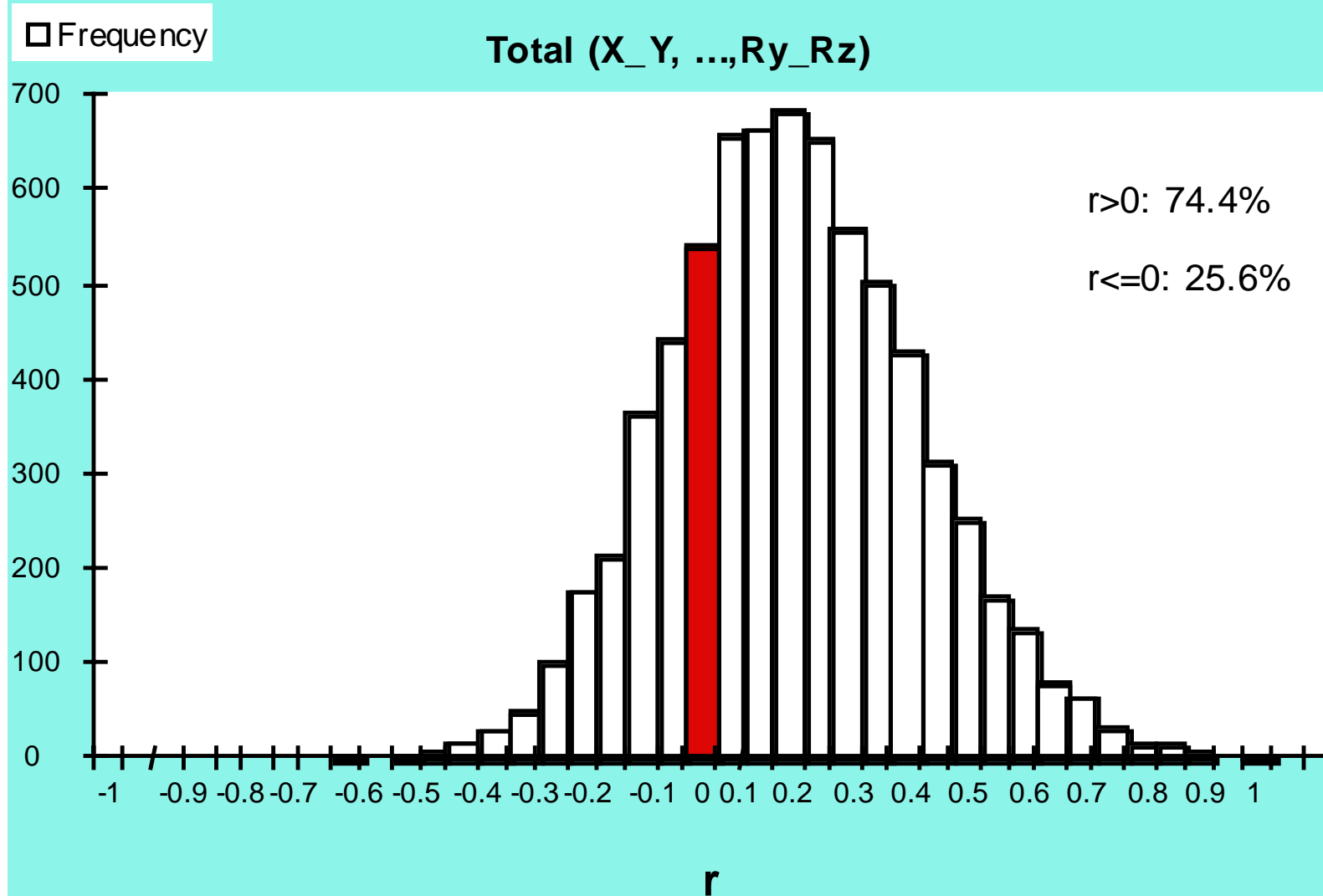


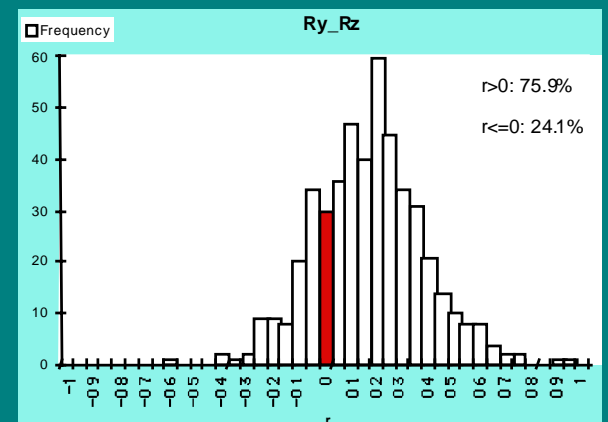
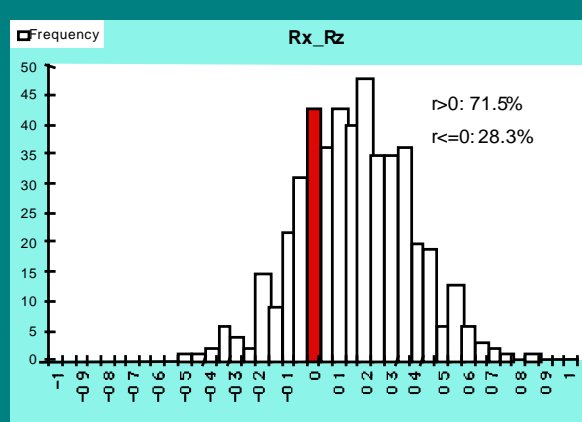
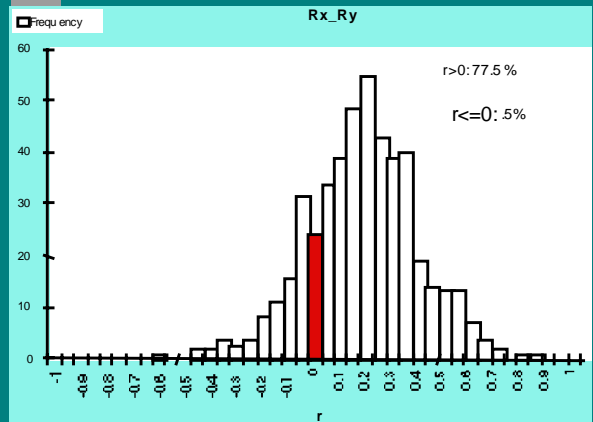
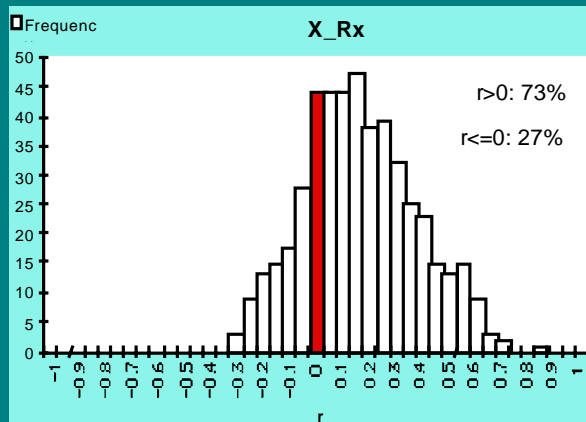
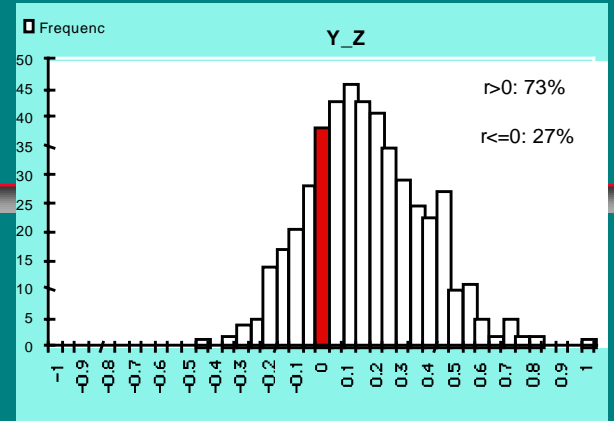
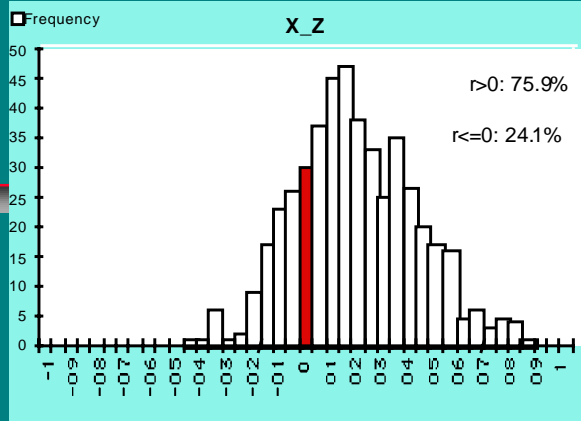
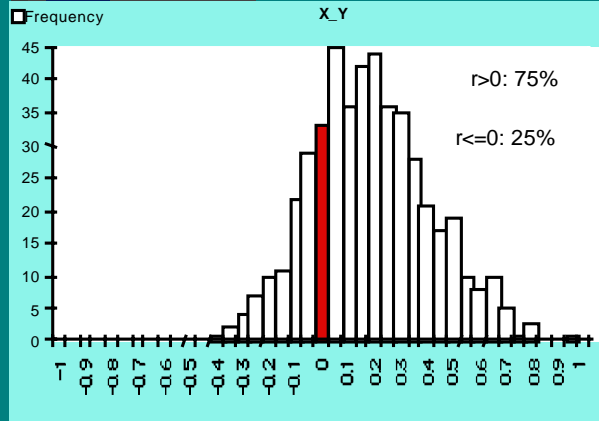
Error correlation analysis

- Correlation as a coordination measure
(Senders *et al* 1955, 1956)



Correlation in 6DOF tracking



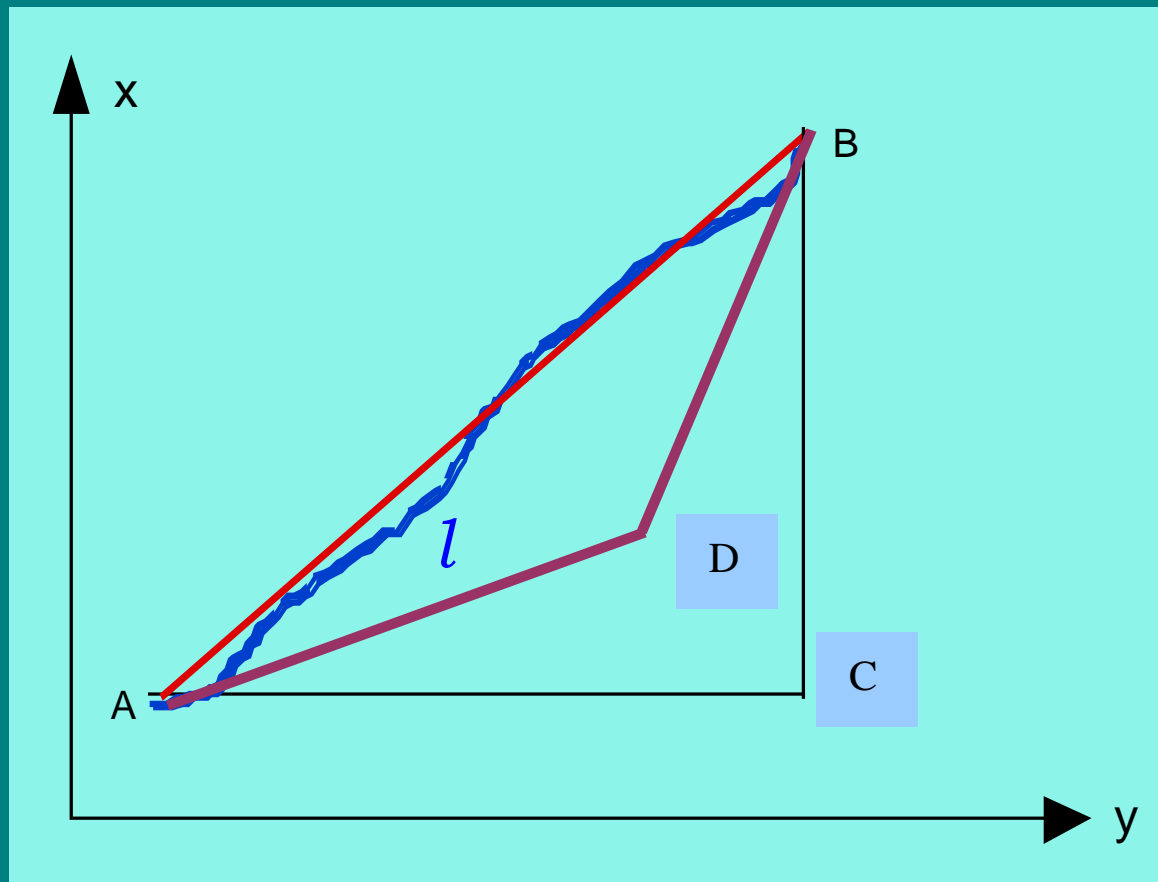


Contrast between current and early results

- *Early studies: Ss could not coordinate multiple (2-3) DOF
(e.g. Ellson 1947, Senders 1956)*
- *Current study: Ss could coordinate multiple (6) DOF*
- *Reason: Design of controls and displays*

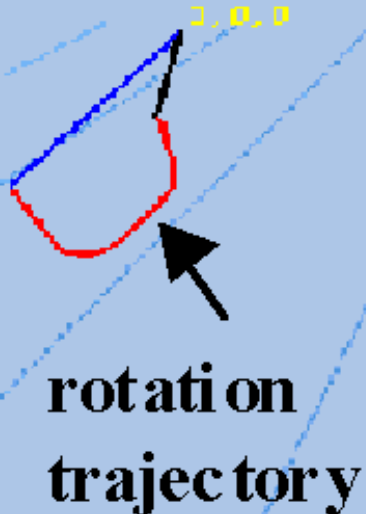
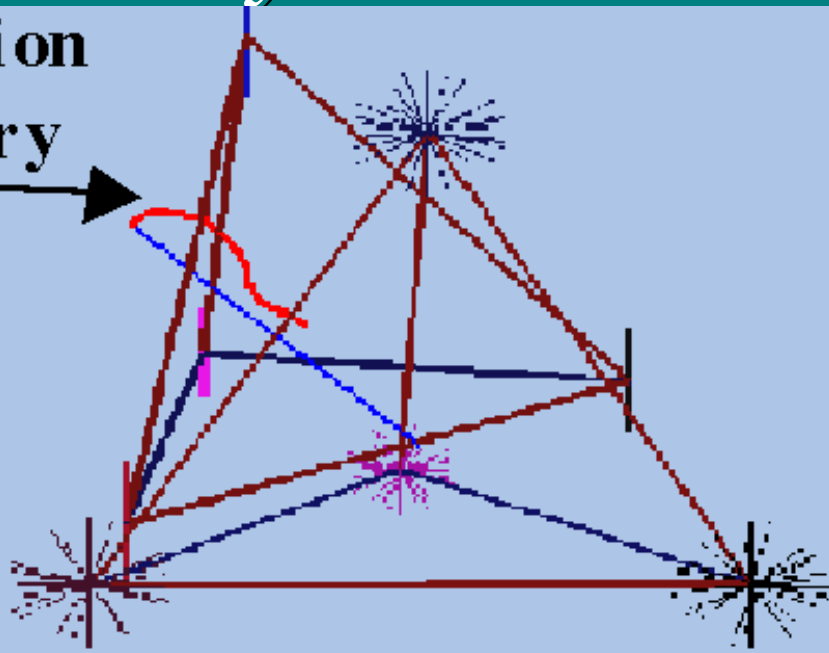
An efficiency-based coordination measure

- *Shortest path in coordination spaces*

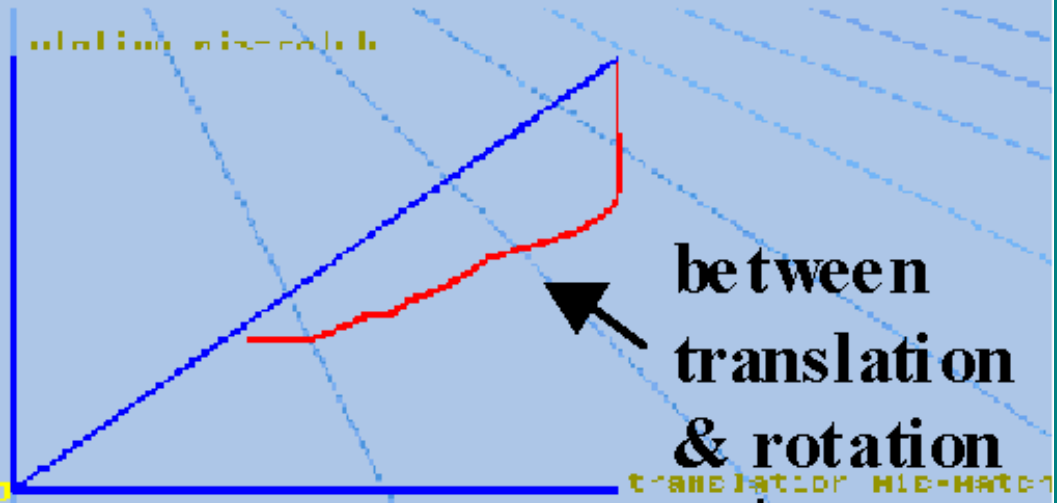


Efficiency in 6 DOF docking

translation
trajectory



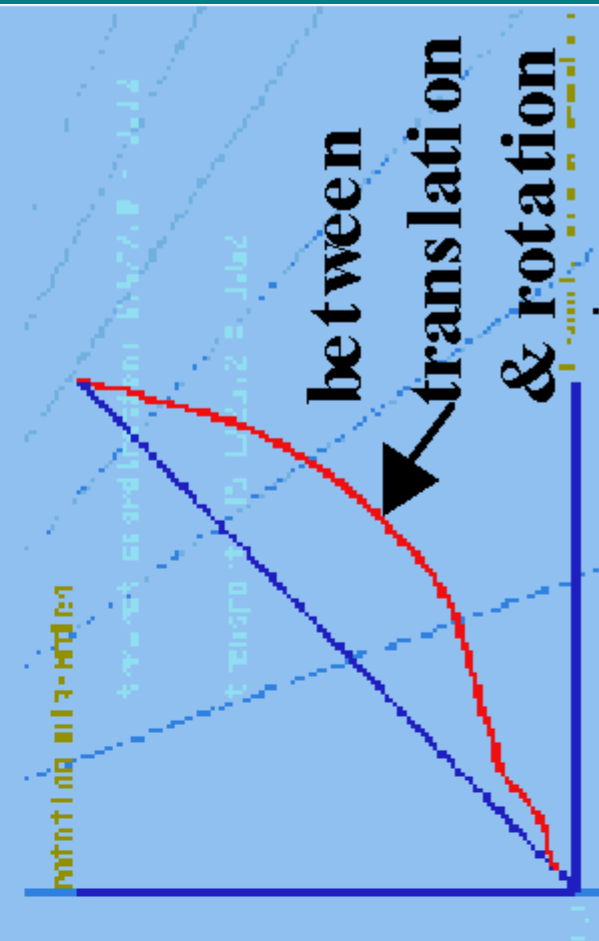
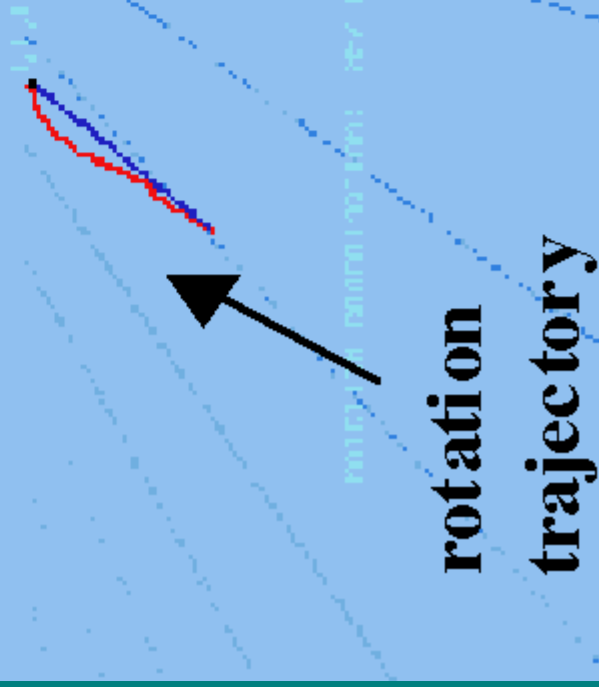
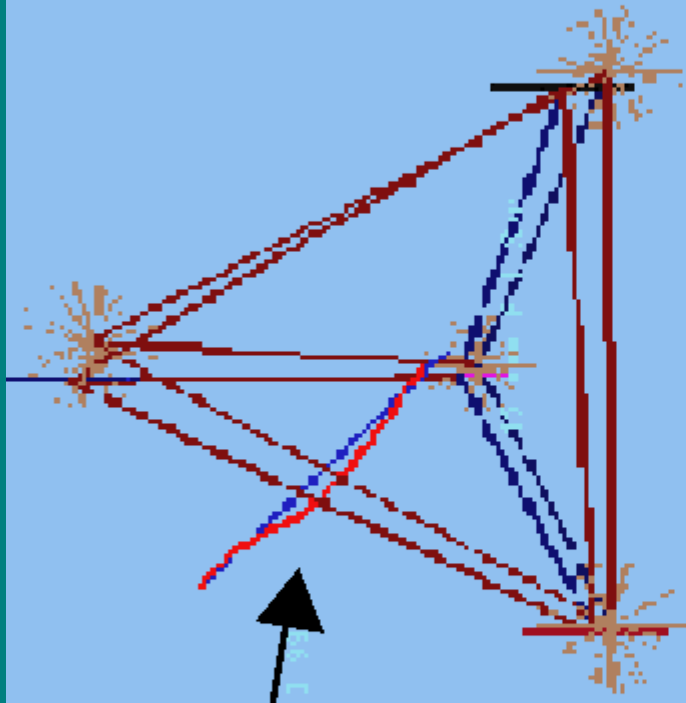
rotation trajectory



between
translation
& rotation

translation trajectory

translation trajectory

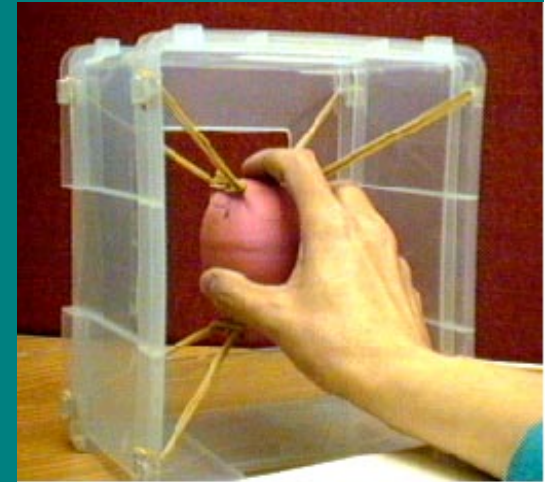


rotation trajectory

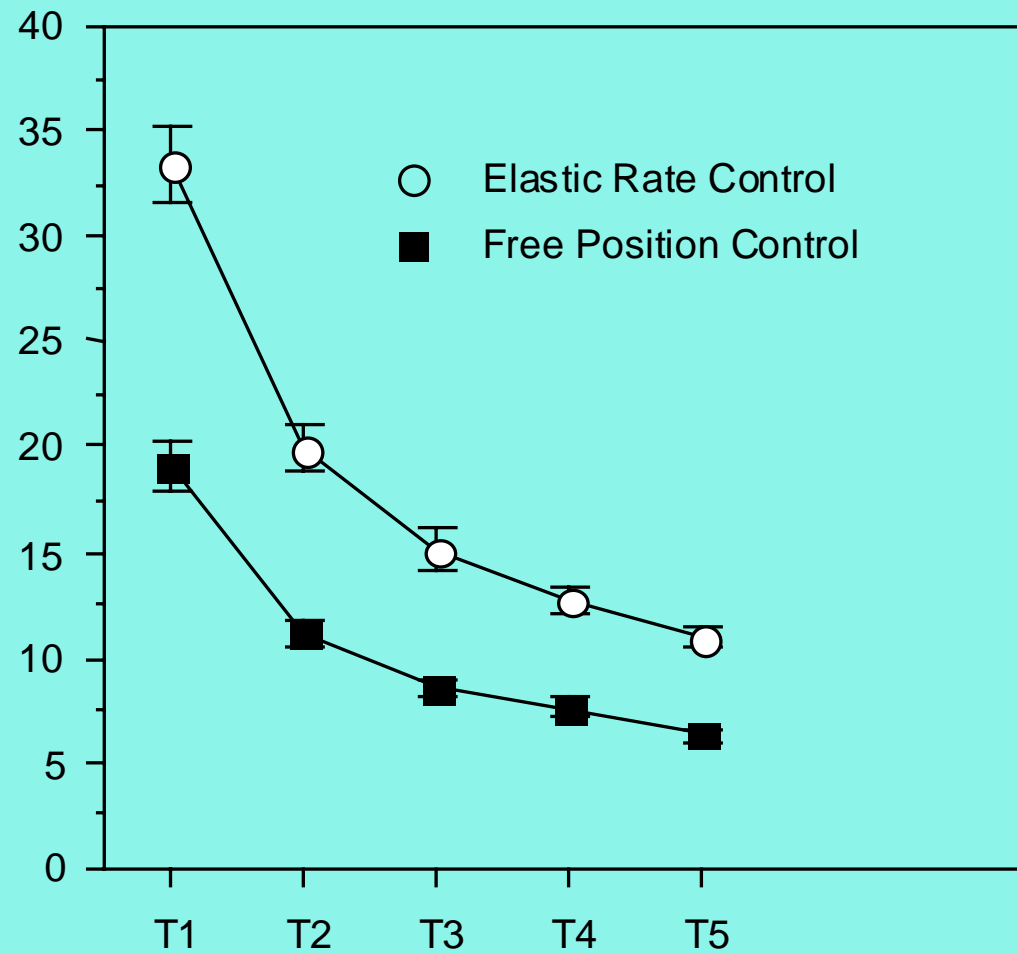
between translation & rotation

Efficiency in 6 DOF docking: experiments

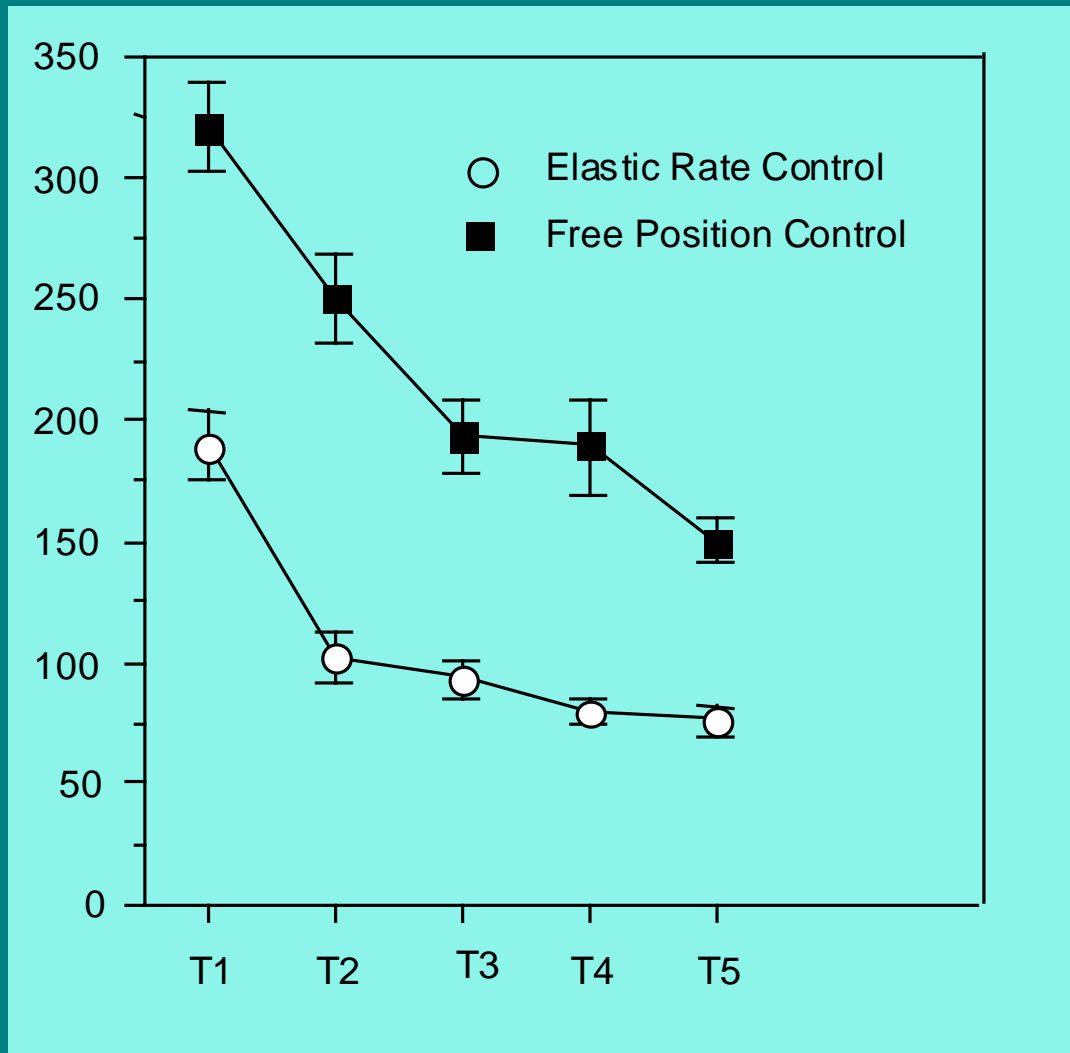
- *32 subjects*
- *Two 6 DOF control devices*
 - *Elastic rate control*
 - *Isotonic position control*



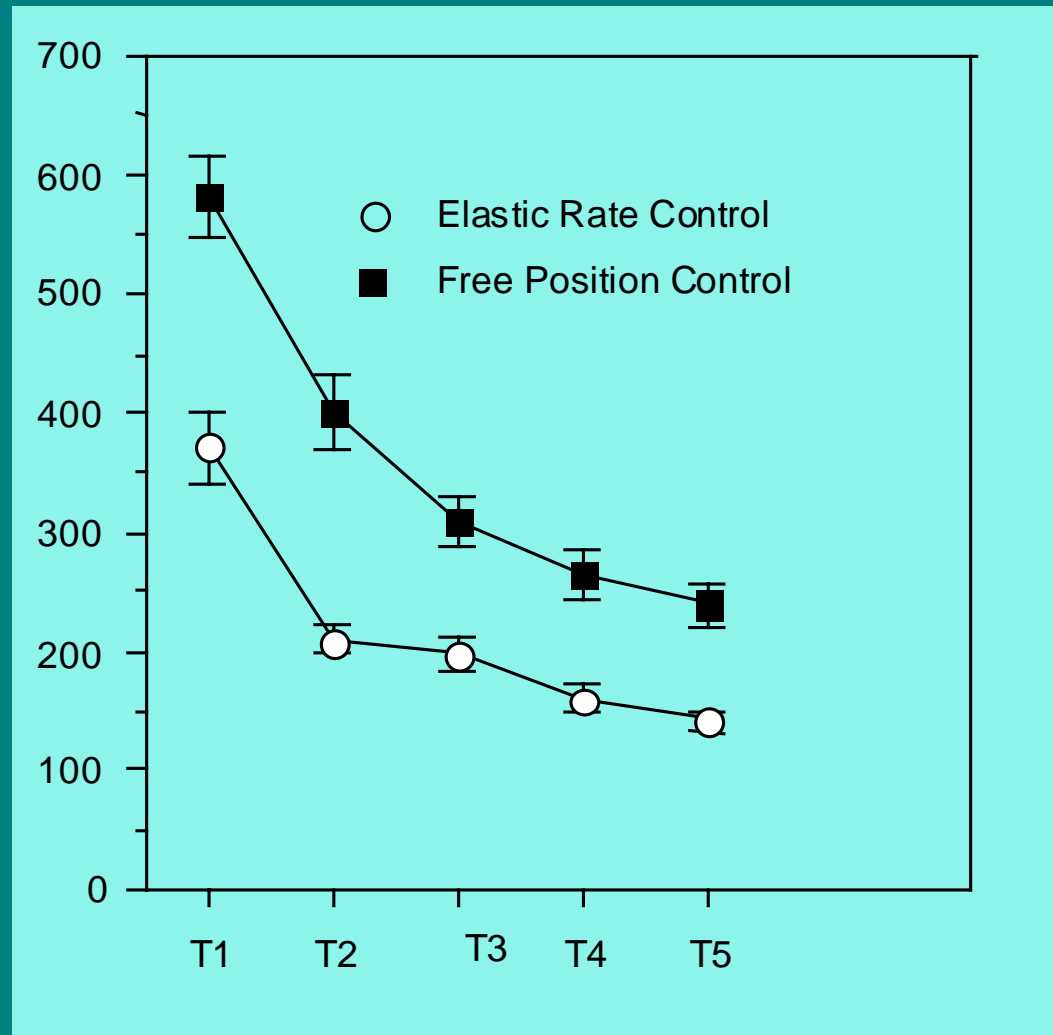
Mean completion time (sec)



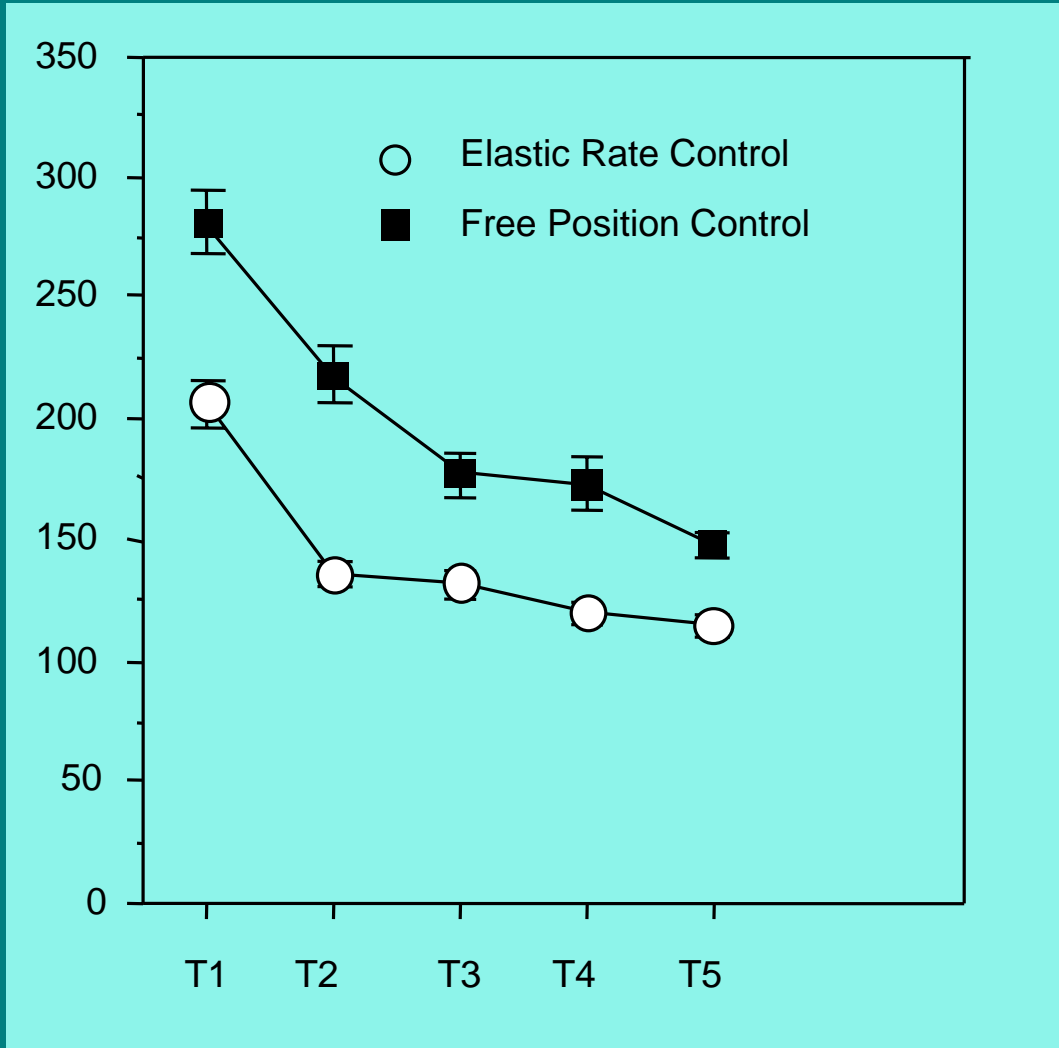
Translation inefficiency (%)



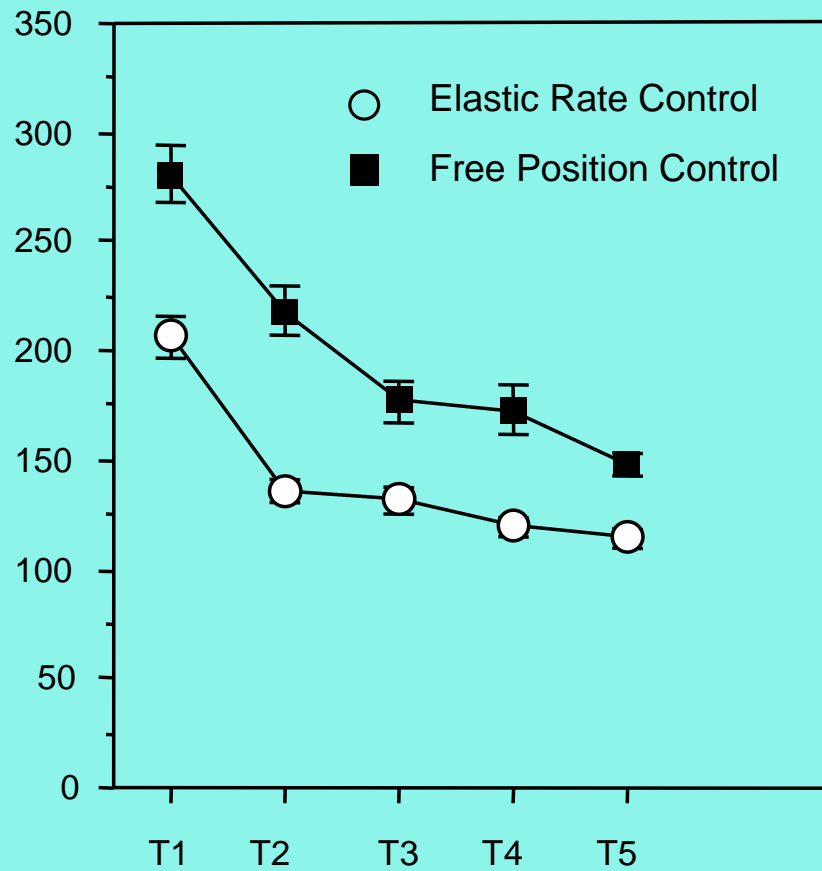
Rotation inefficiency (%)



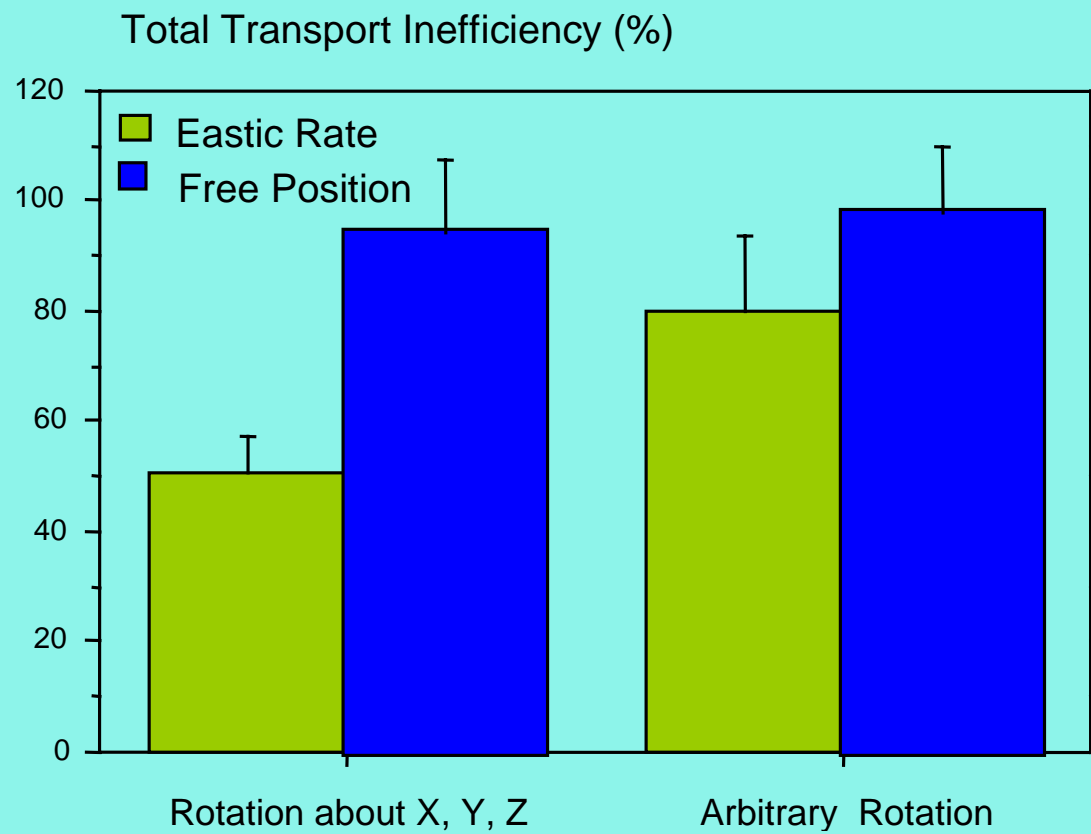
Between translation and rotation (%)



Total Transport



Rotation Type Effects



Isomorphism vs. Tool Using

← Directness Indirectness →

Isomorphism Tools

Transformation	position control			Rate control	Higher order control
	Absolute		Relative (Clutch)		
	C/D Isospace	C/D off-set			
2DOF Examples	Touch Screen	Tablet	Mouse	Joystick	
6 DOF Examples		Fingerball	Glove	Egg Spaceball	

Summary and conclusions

- *A variety of coordination measures*
 - *TOT% (Ellson)*
 - *Correlation (Senders)*
 - *Efficiency (Zhai)*
- *Ss could coordinate 6 DOF (contrary to Ellson 1947 and Senders 1956)*
- *Rate control (tool using) was slower than position control (direct manipulation), but better coordinated*

Acknowledgments

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