Use of feedback for motor learning

Mindy F. Levin, PT, PhD

Canada Research Chair in Motor Recovery and Rehabilitation

Stroke rehabilitation: How effective are we?

- More effective acute management, but number of stroke survivors needing long-term care or rehabilitation increasing — economic burden
- At 6 months post stroke, 50-70% continue to have arm motor deficits, 30% are unable to walk without assistance and 46% have cognitive deficits *(Young and Forster, 2002, Go et al., 2013, Am Heart Assoc, 2014).*
- Mounting evidence that recovery can extend beyond course of usual rehabilitation *(e.g., Cirstea and Levin 2007; Piron et al. 2010)*
- Better recovery related to remediation of underlying motor control deficits through intensive practice and motor learning processes.

Rehabilitation

Motor Learning

Adaptive Plasticity

Behavioral recovery after brain injury

What are we learning?

- ***Recovery*** – accomplishing a movement or task the same way as it was done before
  - also called 'restitution'

- ***Compensation*** – accomplishing a movement or task in a different way than how it was done before. Other terminology: 'adaptation', 'substitution' e.g. use of trunk to extend the reach of the UL

Motor performance
(movement precision, speed, straightness and smoothness)

Movement quality
(joint ROM, trunk movement, interjoint coordination)

Levin, Kleim, Wolf, NNR, 2009

What is normal movement?

Normal movement is characterized by redundancy and adaptability

➔ movement does not repeat itself (Bernstein 1967)

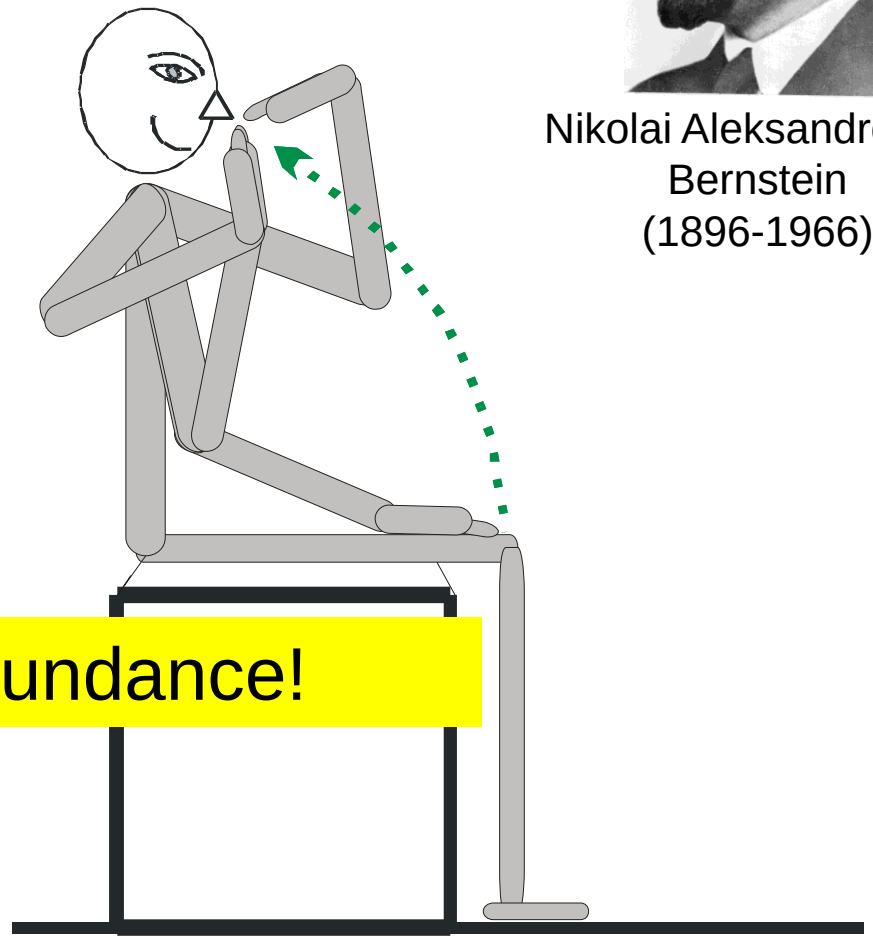
➔ but.. each time we move, we have a unique solution to the redundancy problem

Nikolai Aleksandrovich Bernstein (1896-1966)

Redundancy

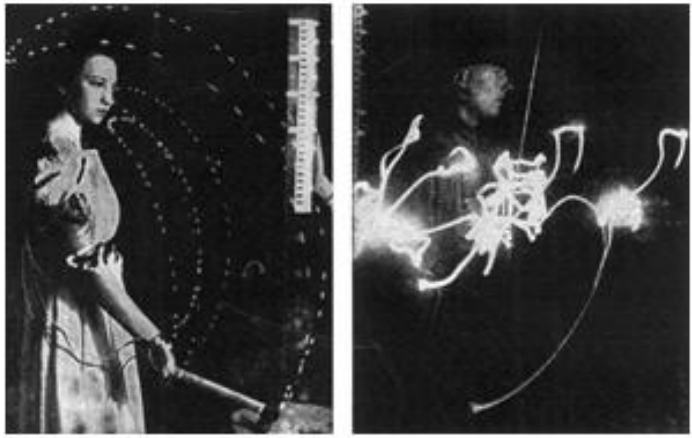
For reaching, there is a minimum of 7 upper limb rotational DFs

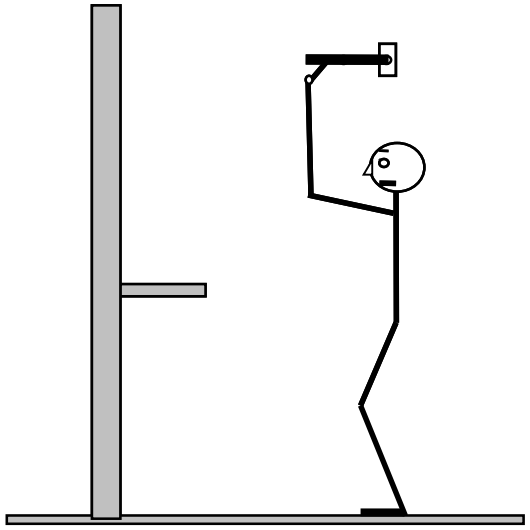
3 shoulder + 2 elbow + 2 wrist

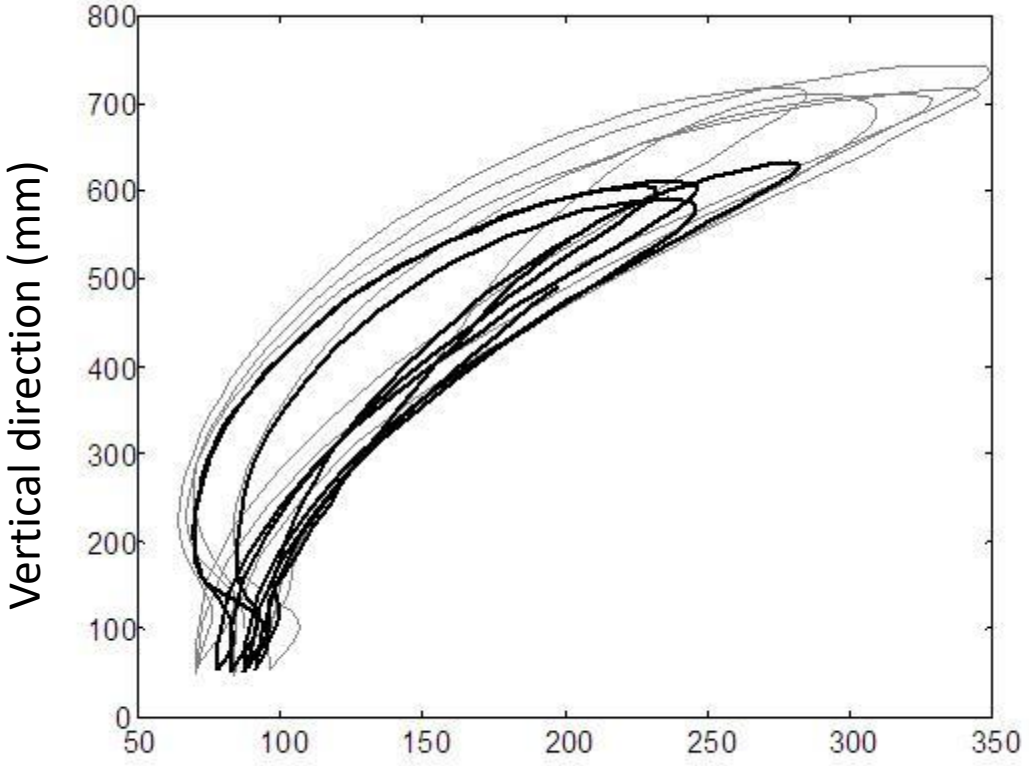


Redundancy = Abundance!

The large number of joint DFs allows us to use different trajectories to achieve the same final position ….



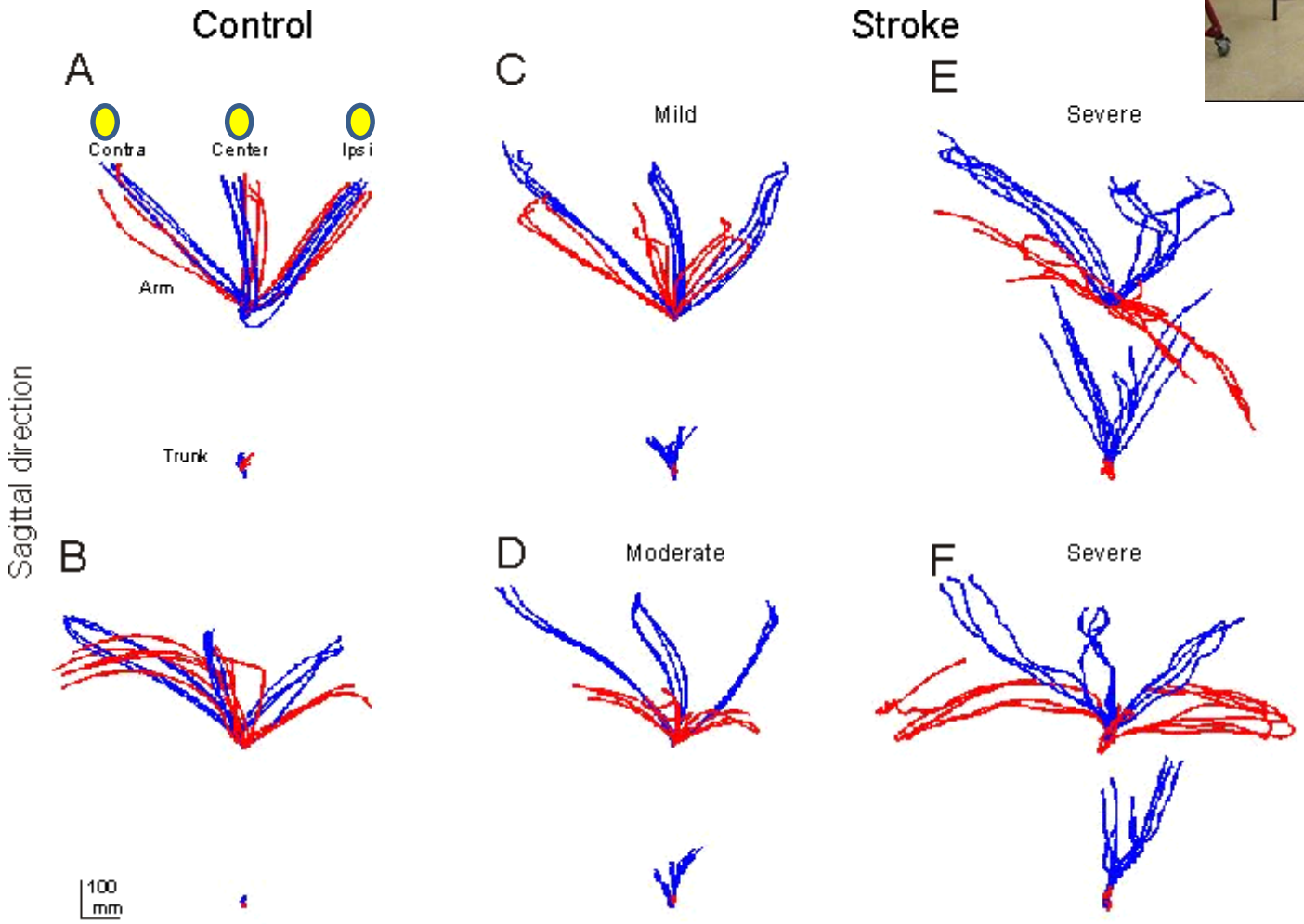




Cote et al., Experimental Brain Research, 146: 394-398, 2002

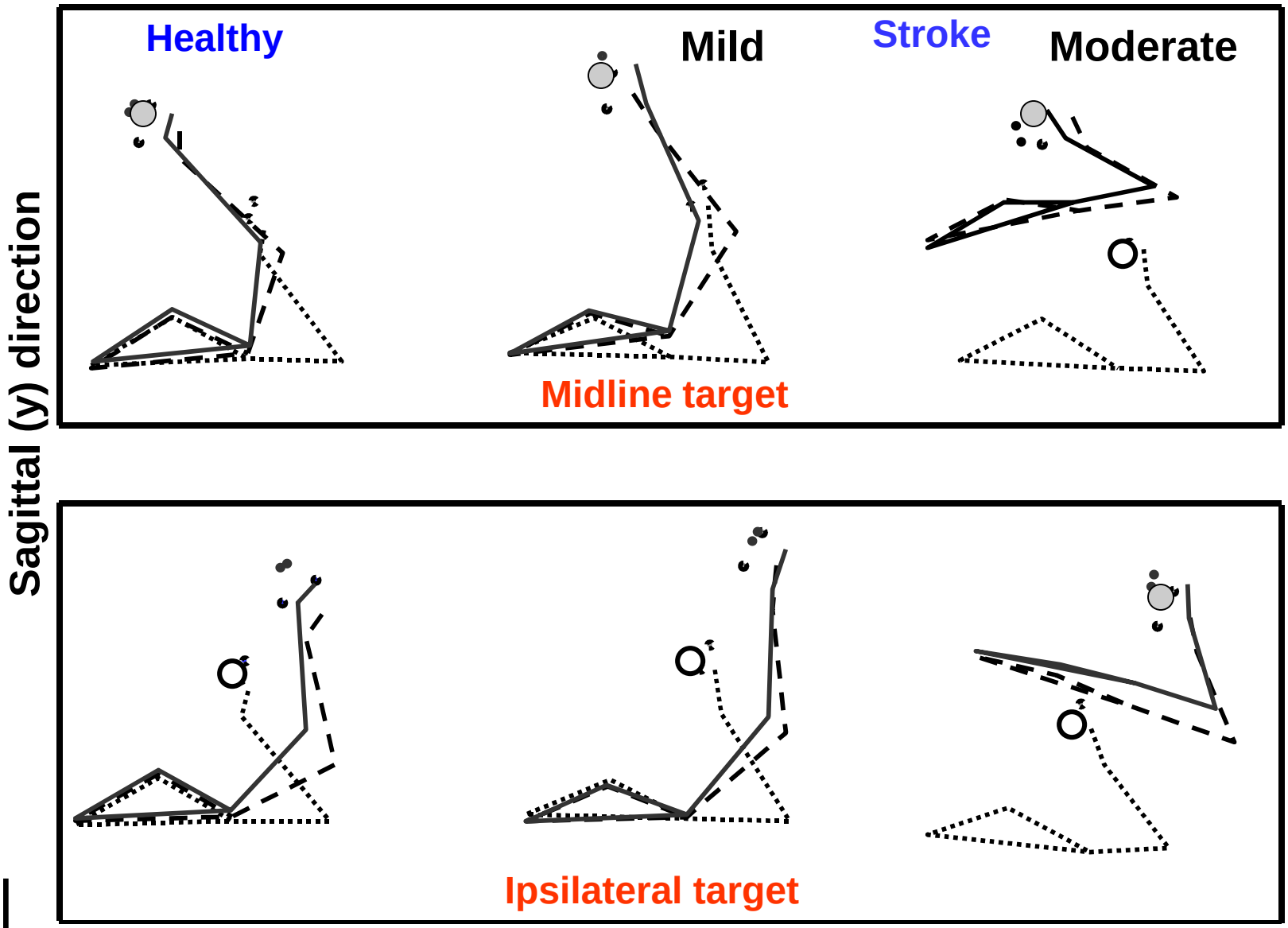
Patients with stroke can use their (limited) redundancy

** often finding non-optimal adaptive solutions to movement problems ➡ motor compensations



Physical
Virtual

Compensation: Substitution of different DFs to achieve the same motor task.



Michaelsen SM et al. 2009

Deficits in movement production in patients with stroke

- Endpoint movements are slower, more curved, less precise and less smooth (Cirstea CM & Levin MF 2000; Subramanian SK et al. 2010)
- Ability to combine movements of different joints in adaptive patterns is limited (Shaikh T et al. 2014).
- Related to deficits in the ability to regulate muscle activation thresholds in particular muscles and groups of muscles (Levin MF et al. 2000; Musampa NK et al. 2007; Mullick AA et al. 2013).
- Better recovery may be related to feedback focused on enhancing endpoint smoothness while diminishing unwanted motor compensations.

Traditional Approach to Motor Learning

❖The internal processes concerning practice or experience leading to a relatively permanent change in the capacity of the subject to respond *(Schmidt and Lee, 2011)*

❖ classic information processing framework that identifies changes from input to output stages of processing *(Fitts 1964, Schmidt 1987)*

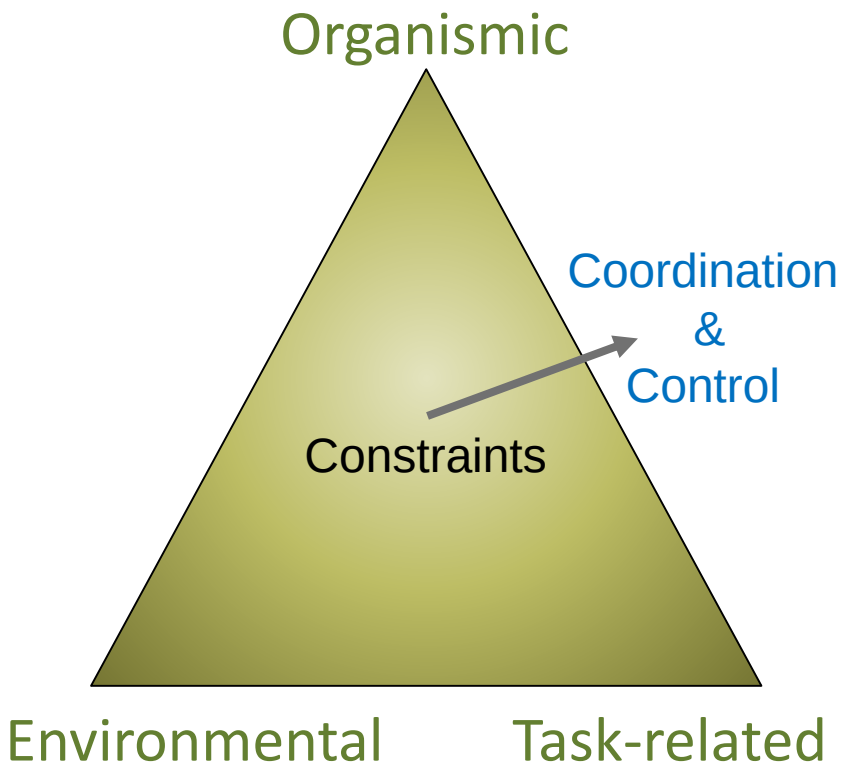
behavior change

retention

transfer

Dynamical Approach to Motor Learning

Emphasizes dynamics of change in the movement sequence and its outcome over practice



- Draws on general idea of Bernstein that skill learning is reflected in the mastery of redundant degrees of freedom (DFs).
- Is a problem-solving system that uses available constraints and possibilities to discover solutions to a movement problem.
- Acquiring coordination is not hampered by the many interacting variables (i.e., joint DFs) but simplified by them.
- Allows exploitation of the natural properties of the system.
- Emergent rather than reductive approach.
- Gives rise to adaptability based on task demands and constraints.

Thelen, 1995; Newell 1996; van Dijk et al. 2016

Types of Motor Learning

Characteristics	Model: Traditional Information processing	Model: Dynamical Self-organizing
Approach	Reductive – focuses on reducing impairments at the ICF Body Structure and Function level	Emergent – focuses on improving problem-solving at the ICF Activity level
Type of learning	Explicit	Implicit
Type of practice	Traditional (action repetition)	Differential (tactionvariability)
Type of feedback	Internal focus	External focus

Ten principles of experience-dependent neural plasticity

Kleim JA and Jones TA. J Speech Lang Hear Res 51:5225, 2008.

1. Use it or Lose It
2. Use it and Improve It
3. Specificity
4. Repetition Matters
5. Intensity Matters
6. Time Matters
7. Salience Matters
8. Age Matters
9. Transference
10. Interference

Motivation

Fun!

Motivation

- crucial for motor learning

Dopaminergic projections from ventral tegmental area (signaling reward) to primary motor cortex mediate motor skill learning (Hosp et al, 2011)

Behavioral research supports motivational effects (including perceived competence) on motor learning (Krakauer 2006, Kleim 2008, Lewthwaite and Wulf 2012)

Reward improves long-term skill retention

(Abe et al. Curr Biol. 2011)

Practice Intensity

- High intensity practice → better outcomes.

Intensity =

- → Duration, active time in therapy
- → Number of repetitions

Lohse et al., 2014

Feedback: Internal vs external focus of attention

Internal focus: attention is directed at the movements composing the motor action

External focus: attention is directed at the effect of the movement: goal

Feedback delivery schedule

Continuous (after every trial)

Summary (after a fixed number of trials, general information about all trials)

Average (average information about a fixed number of trials)

Faded (initially after very trial, then after several trials)

Faded feedback →

- More opportunity to find own motor solution
- Better retention of learned skills

(Hebert et al., 1998, Cirstea et al., 2006)

Feedback – Knowledge of Results (KR)

- **Positive feedback** - movement is both temporally and spatially successful (high pitched ‘ping’ sound, target turns green)

- **Negative feedback** - movement is not rapid and/or precise enough (buzzer sound, color of the target does not change)

Feedback – Knowledge of Performance (KP)

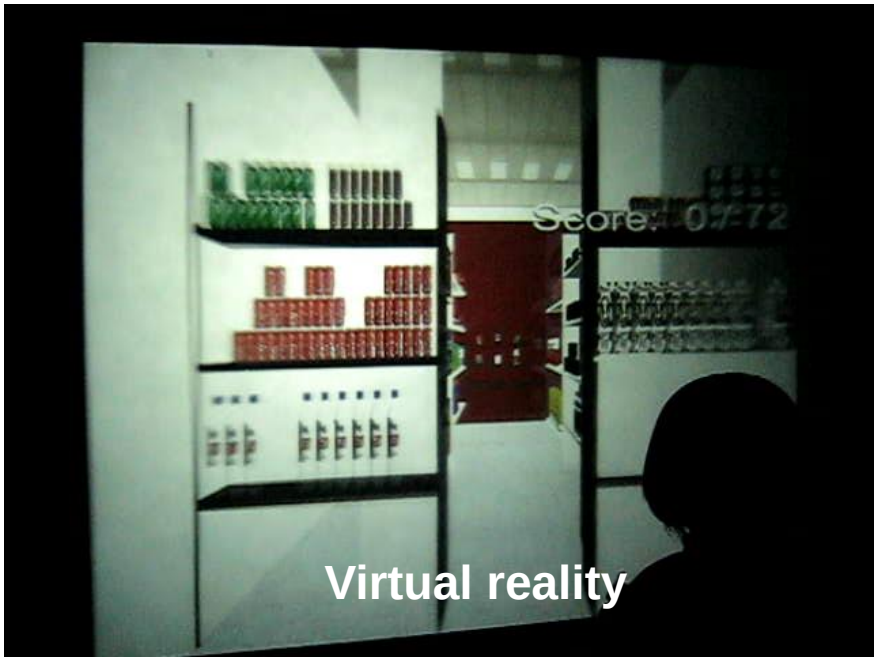
- **Excessive trunk motion** – 3rd sound emitted ('whoosh'), target turns red (even if the subject's movement was accurate and precise enough)

- Default value for permissible trunk displacement tolerance adjustable (i.e. 5 cm)

Treatment Approaches

General:

- Identify characteristics of those individuals most likely to benefit from different interventions – motivation, task relevance
- May be beneficial to combine different technologies for maximal effectiveness.



Treatment Approaches

Specific:

Type of Feedback

- Increase restricted control ranges
  - Target task practice to work within and increase active control zones

  Negative FB – excessive EMG

- Strengthen key muscles within active control zones in task-relevant patterns (i.e., shoulder flexion with external rotation).

  Positive FB – force output
  Negative FB - compensations

- Find solutions based on limited redundancy / increase redundancy

  Negative FB – compensations

- Encourage active problem-solving – learning by exploration

  Positive FB – task outcome

Acknowledgments

- Sandeep Subramanian
- Eliane Magdalon
- Christiane Lourenco
- Luiz Alberto Knaut
- Melanie Banina
- Marika Demers
- Ruth Dannenbaum
- Rhona Guberek
- Christian Beaudoin, Valeri Goussev
- Anatol Feldman