PERCEPTUOMOTOR ADAPTATION: MORE THAN MEETS THE EYE

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Psychonomic Society 2002

Overview

- Three perceptuomotor aftereffects
- A ceiling effect in one of them
- A multi-modal model to explain it
- Use VR to test a model prediction

Three aftereffects to sensory conflict during locomotion

- Treadmill locomotion produces a conflict between motor activity and sensory feedback.
- This can lead to
  1. inadvertent DRIFT when attempting to run in place (Anstis, 1995)
  2. OVERSHOOT when attempting to walk without vision to a previewed target (Rieser et al., 1995), and
  3. an exaggeration of visual FLOW (Pelah & Barlow, 1996) (Attributed to contrast with expectancy.)
- All consistent with an underestimation of self-motion from the motor system.

Three aftereffects or just one?

What is the role of vision during adaptation?

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What is the role of vision during adaptation?

1. Anstis (1995) claimed his effect was specific to treadmills, and did not involve vision. Durgin & Pelah (1999) showed that the DRIFT effect could be induced by running on solid ground with eyes closed, not with eyes open (perceptuo-motor conflict).

Surface

Eyes		Treadmill	Ground
	Open	YES	NO
	Closed	YES	YES

Three aftereffects or just one?

What is the role of vision during adaptation?

2. Rieser et al. (1995) claimed their effect <u>required</u> the presence of visual feedback during adaptation. Durgin et al. (ARVO 1998; VSS 2000) showed that OVERSHOOT was produced by treadmill running or walking with eyes closed (there is haptic feedback from treadmill rails).

Adapted Speed

		4 kph (2.4 mph)	8 kph	7 kph (walk)
Eyes	Open	**YES** ~ 10%	**YES** ~ 18%	
	Closed	**NO** - 4%	**YES** ~ 17%	**YES** ~ 17%

Three aftereffects or just one?

What is the role of vision during adaptation?

3. Pelah & Barlow (1996) claimed that the FLOW effect was much stronger when adapted with eyes open. Fox & Durgin (VSS 2002) showed that the DRIFT effect could be measured by gain-matching in VR and that similar aftereffects emerged after treadmill walking with and without vision (about 10% shift).

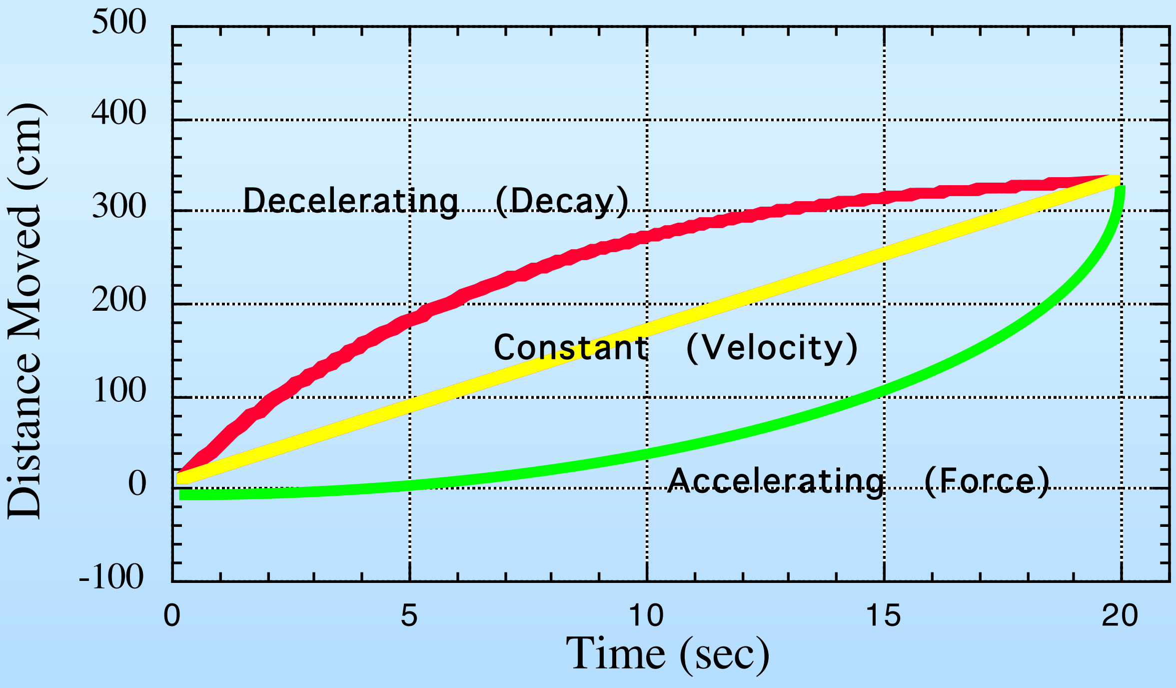
Treadmill speed

Eyes		8 kph	5 kph (static VR)
	Open	YES +30%	YES +10%
	Closed		YES +10%

VR gain matching (FLOW) after walking without flow.

What is the adapted variable?

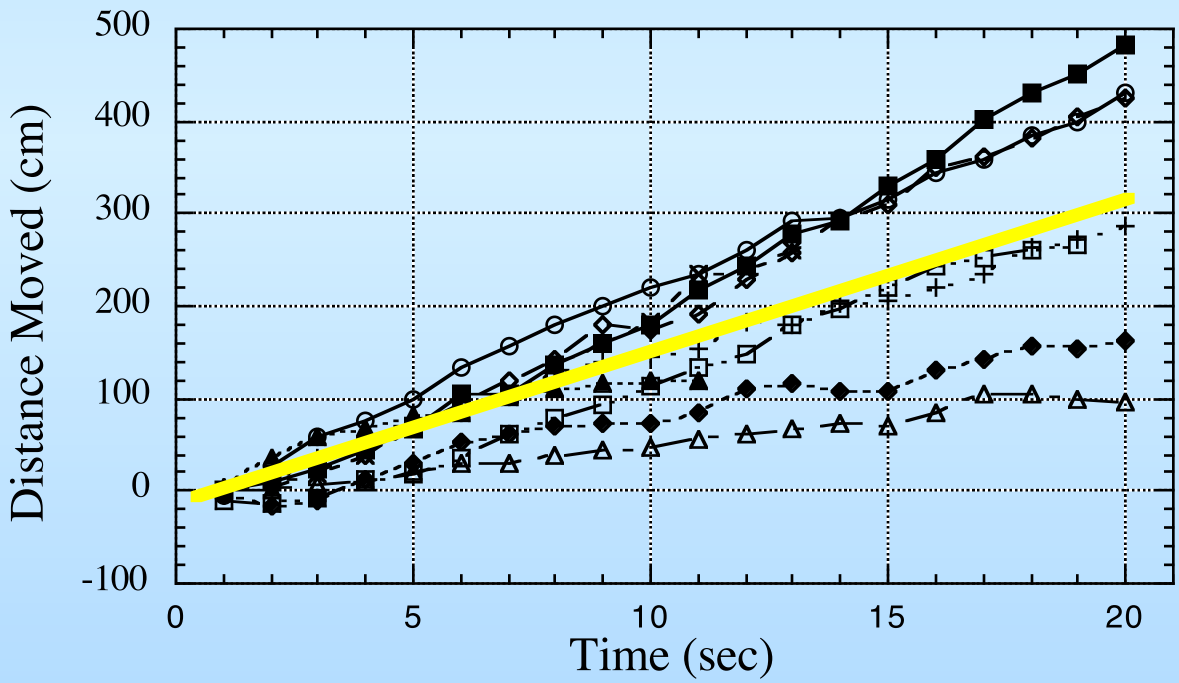
- DRIFT effect: Velocity? Acceleration?



Theoretical location x time while “running in place”

What is the adapted variable?

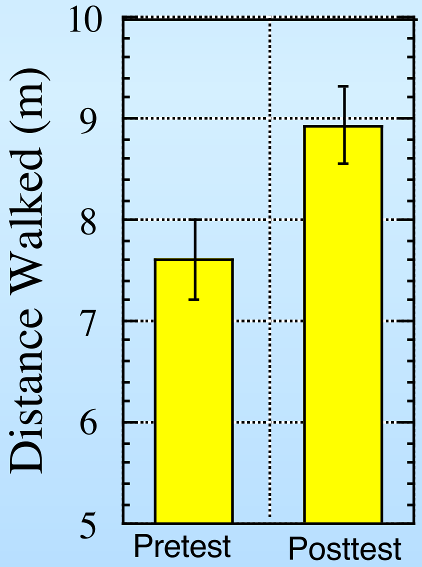
- DRIFT effect: It seems to be velocity:

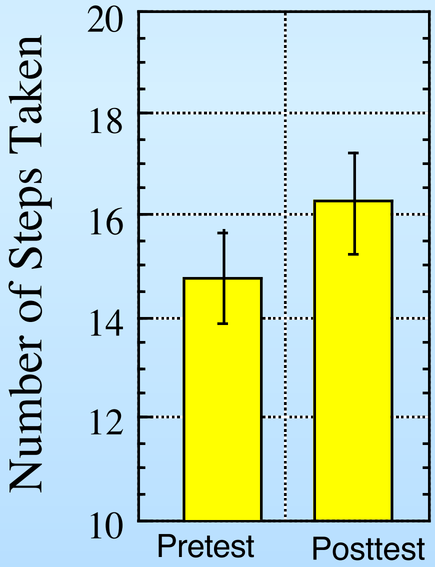


Drift: Location while “running in place” over time

What is the adapted variable?

- OVERSHOOT: consistent with velocity…
  (I.e., perceived distance traveled per step.)





Walking to previewed target before and after running on treadmill with eyes closed

What is the adapted variable?

- FLOW: explicitly relative velocity...

Interim conclusions:

1. Visual information modulates all three effects, but all three can be generated with eyes closed.

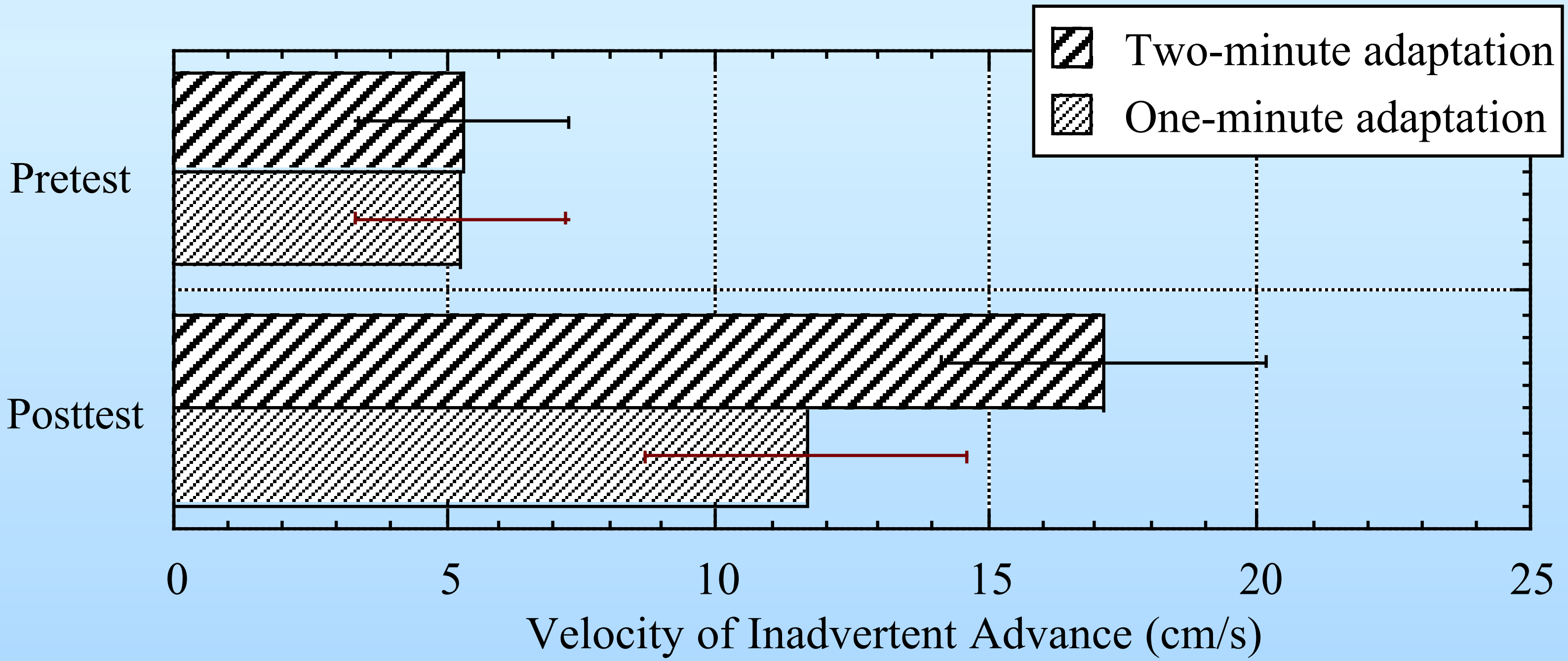
2. Adapted variable is “motor” estimate of velocity of self-motion.

Part 2

The Anomaly:

Evidence for a ceiling effect in OVERSHOOT tasks.

- The DRIFT aftereffect shows predictable modulation by such variables as time of adaptation and treadmill speed.



A ceiling effect in OVERSHOOT

OVERSHOOT, on the other hand, appears to be modulated neither by time, nor by speed.

	Motor Speed	Visual Speed	Time	Overshoot	Source
TIME	9	0	1 min.	15%	Durgin et al. (2000)
	9	0	2 min.	15%	Durgin et al. (2000)
SPEED	10	0	2 min.	15%	Durgin et al. (1998)
	8	0	2 min.	17%	Durgin et al. (1998)

OVERSHOOT actually demonstrates a ceiling across a number of studies…

Motor Speed	Visual Speed	Time	Overshoot	Source
8	5	8 min.	18%	Rieser et al. (1995)
8	4	8 min.	25%	Rieser et al. (1995)
8	4	8 min.	15%	Rieser et al. (1995)
10	5	8 min.	17%	Rieser et al. (1995)
10	5	8 min.	9%	Rieser et al. (1995)
10	5	8 min.	18%	Rieser et al. (1995)
10	0	2 min.	15%	Durgin et al. (1998)
8	0	2 min.	17%	Durgin et al. (1998)
9	0	1 min.	15%	Durgin et al. (2000)
9	0	2 min.	15%	Durgin et al. (2000)
7	0	1 min.	17%	(Durgin, unpublished)

Part 3

A multi-modal model...

Problems with visuo-motor model

Visuo-motor model

- Conflict between flow and motor estimates of speed; or simply recalibration of motor estimates with respect to visual feedback.

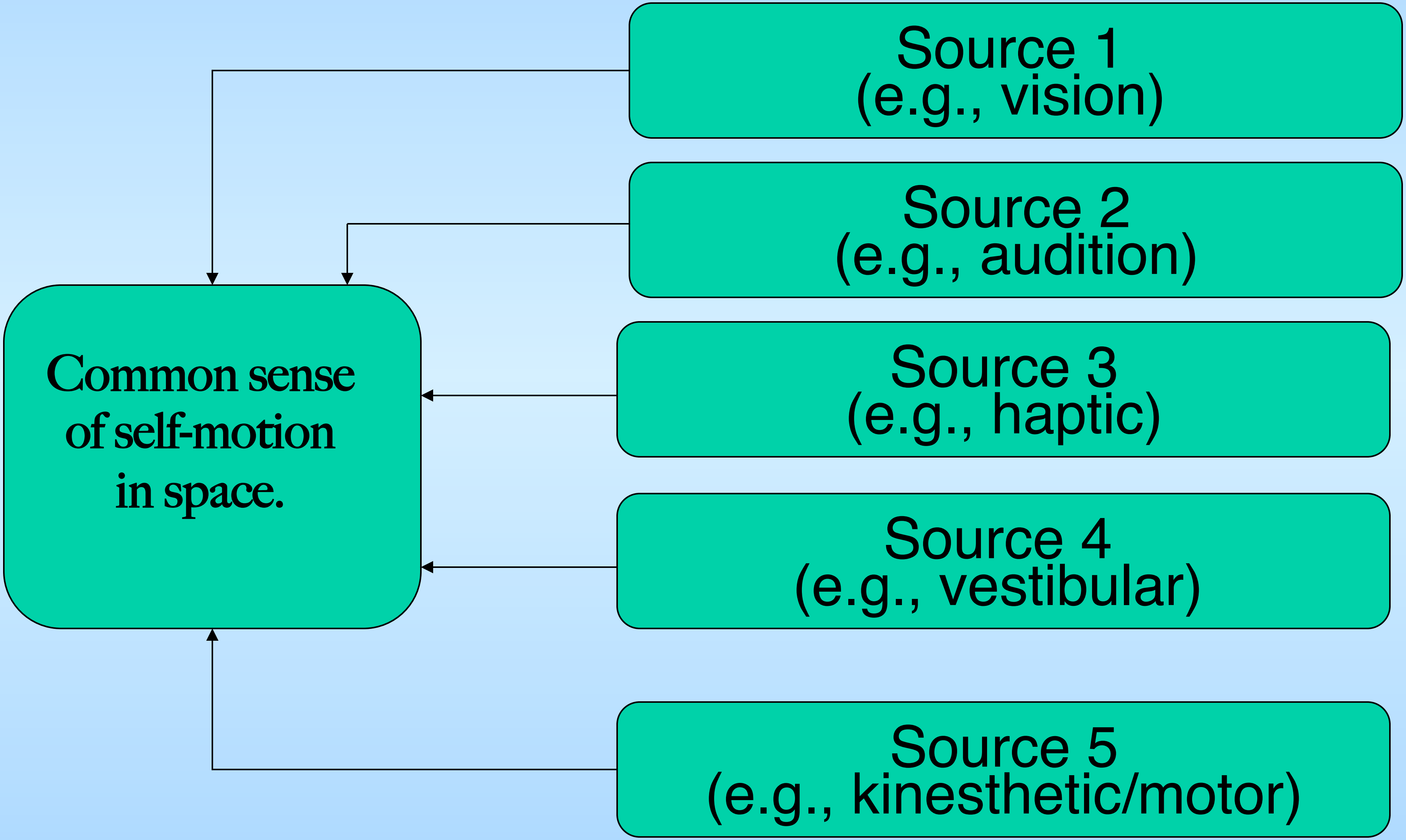
- Contraindications:
  - All 3 adaptations can occur with eyes closed.
  - Supplying optic flow largely fails to alleviate the drift adaptation (Durgin & Pelah, 1999; but see Durgin et al., ARVO 1999, Proffitt et al. in press).
  - Congenitally blind individuals show DRIFT effect (Anstis, 1998, personal communication).

Multi-modal estimator model:

Multi-modal estimator

- Integrates and inter-calibrates multiple kinds of information
- Usually calibration is with respect to vision (visual dominance)
- Conflict is between the individual motor estimate and internal multi-modal estimator

Multi-modal estimator model:



Explaining the ceiling effect

- Assume that some third source of information exists (not vision, not motor) that also provides an estimate of self-motion.
- In the absence of vision, that third estimator might limit the walking error produced by the distorted motor estimate.
- Vestibular information, for example, would likely affect the walking task, but not the running-in-place task.

Hypothesis

- If vestibular signals are adapted with respect to a visually-informed estimate at the same time as the motor signals are adapted, then a stronger overshoot effect might obtain (ceiling pushed back or eliminated).

(This wouldn’t occur with constant velocity adaptation paradigms because the vestibular system provides no estimate with extended constant velocity.)

Part 4

Smashing through the ceiling:

Adapting in walk-through VR

Experimental Question

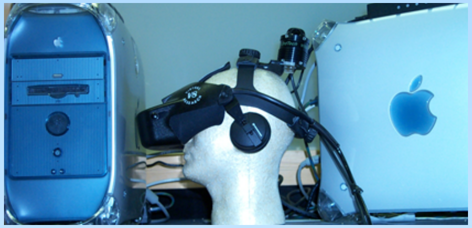
Will adaptation to real walking (including physical accelerations and decelerations) with altered gain produce a more powerful OVERSHOOT/UNDERSHOOT effect?

Design (2 x 2, between)

- Half do walking task pre and post adaptation.
- Half do verbal distance estimation pre/post.

- Half each are adapted to FAST world.
- Half each to SLOW world.

Swarthmore Virt Envir Nav Lab



(“SVENLab”)

Tracker: 3rdTech Hiball™ 3000 tracker

Infrared optical tracker -- exceeds 1000 Hz

Covers ~ 2 x 15 m hallway.

HMD: VRS V8 (stereo, 60° diagonal FOV)

CPUs: 2 G4s for graphics (one for each eye)

plus tracker CPU and controller G4

Images: 120 Hz rendered (640 x 480) (RADEON)

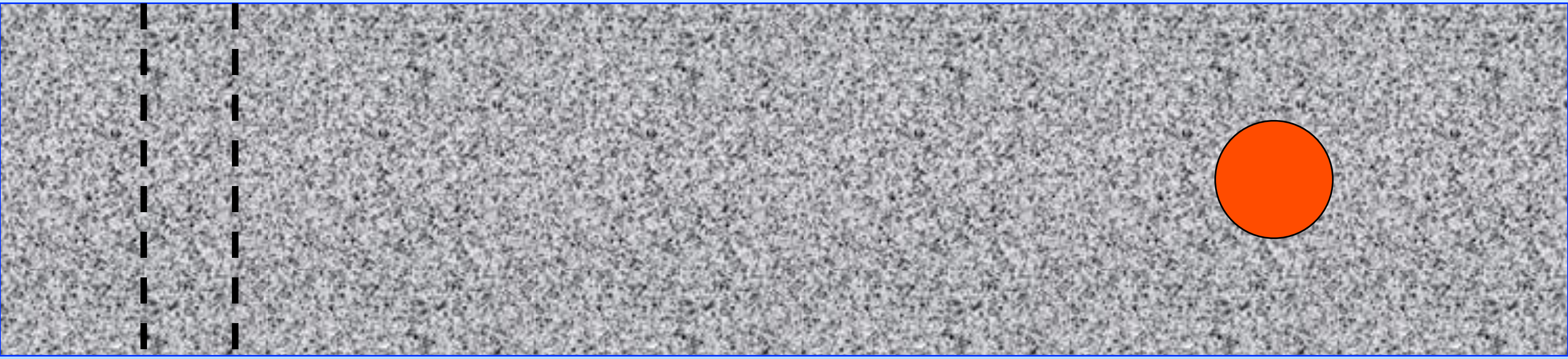
60 Hz displayed (2-frame accumulation buffer)

Procedure (pre)

0. **Practice walking fast (4 kph -- normal pace) while holding VR helmet.**

1. **Practice distance task (motor or verbal) (6.5 m and 3.5 m)**
   VE is only visible from small area -- cannot move much.

2. **Do four pretest distances (2 and 8 m and then 4 and 6 m).**
   Red target cylinder is of random height and diameter.

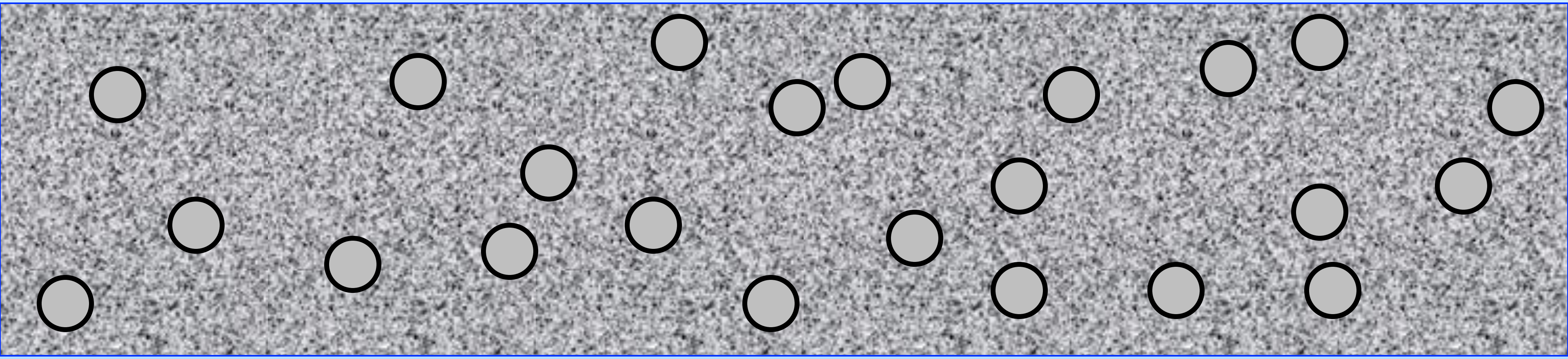


Virtual world: 2 x 2.5 x 100 m hall; texture on walls, floor, and ceiling

Procedure (adapt)

3. Adaptation: 25 times walking up and down hall (9 m) at about 4 kph. Changes in head position along hall axis were multiplied by either 0.5 (SLOW) or 2.0 (FAST). About 4-5 minutes total.

Note: This hall-axis gain manipulation leaves intact the motion-parallax distance cues from lateral head motion.

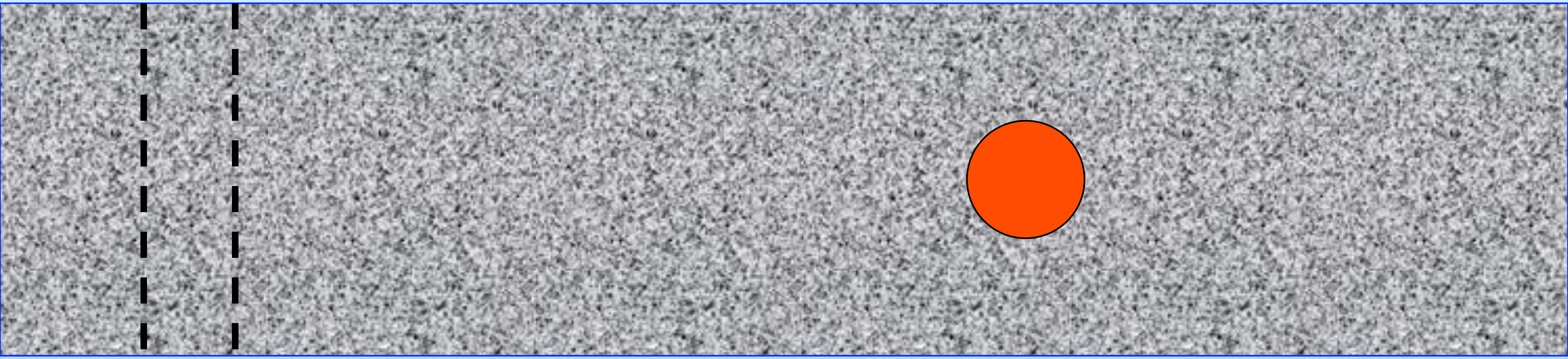


Virtual world: same as test, but dotted with textured columns

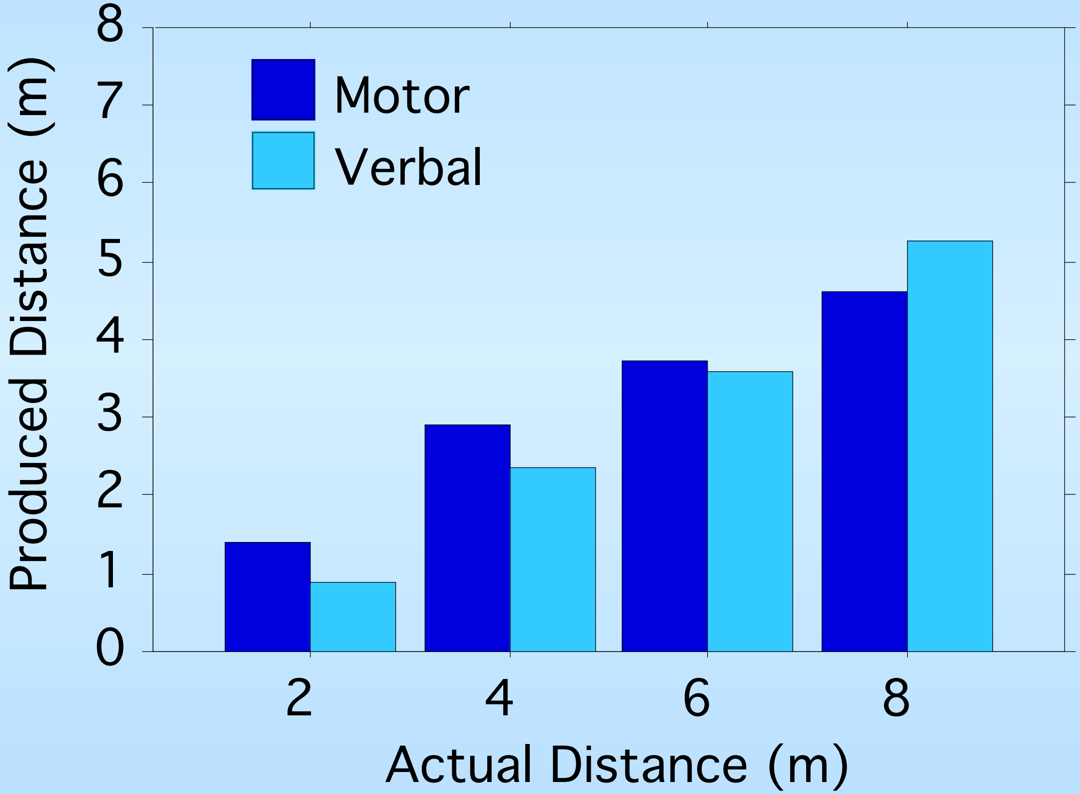
Procedure (post)

4. Do three posttest distances (5 and then 3 and 7 m) -- same world and columns as pretest.

5. Questionnaire at end about VR experience/impressions.



Results (pretest)



Motor ratio: 0.65

Motor exponent: 0.89 (less than 1, $p<.05$)

Verbal ratio: 0.47

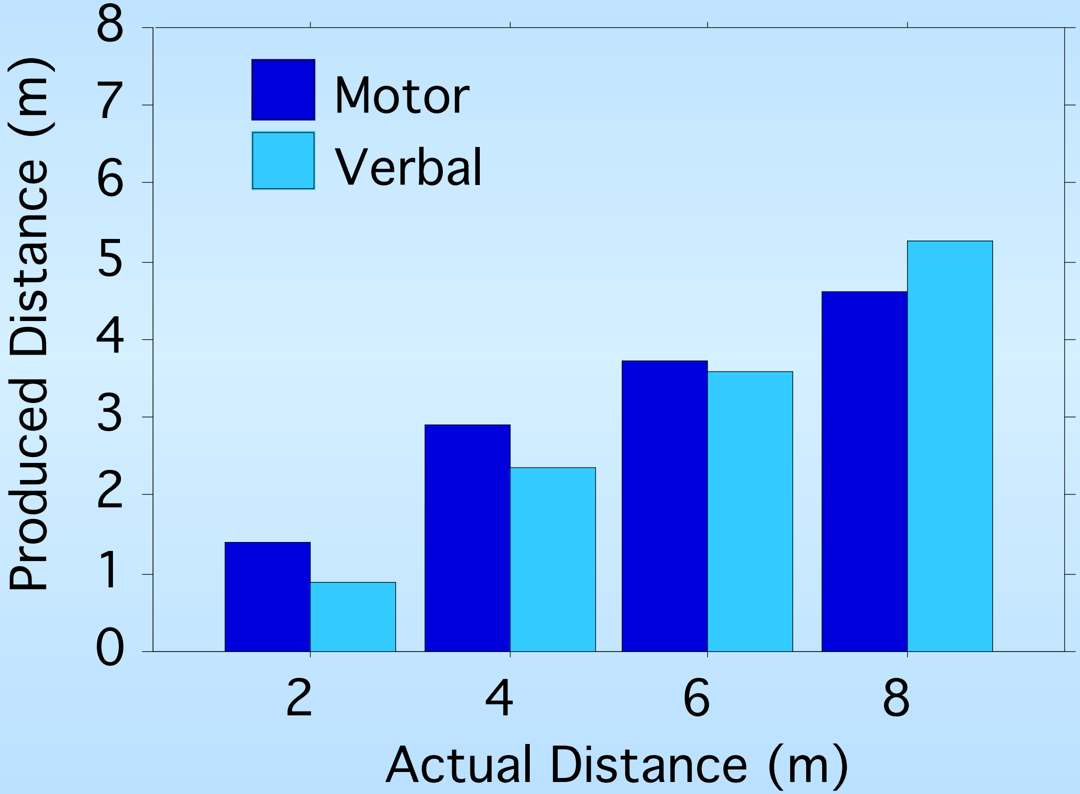
Verbal exponent: 1.39 (more than 1, $p<.005$)

Verbal /Motor ratio: 0.72

Replicate distance underestimation often reported for VR.

Replicate further underestimation (72%) of verbal vs. motor.

Results (pre)



Motor ratio: 0.65

Motor exponent: 0.89 (less than 1, $p<.05$)

Verbal ratio: 0.47

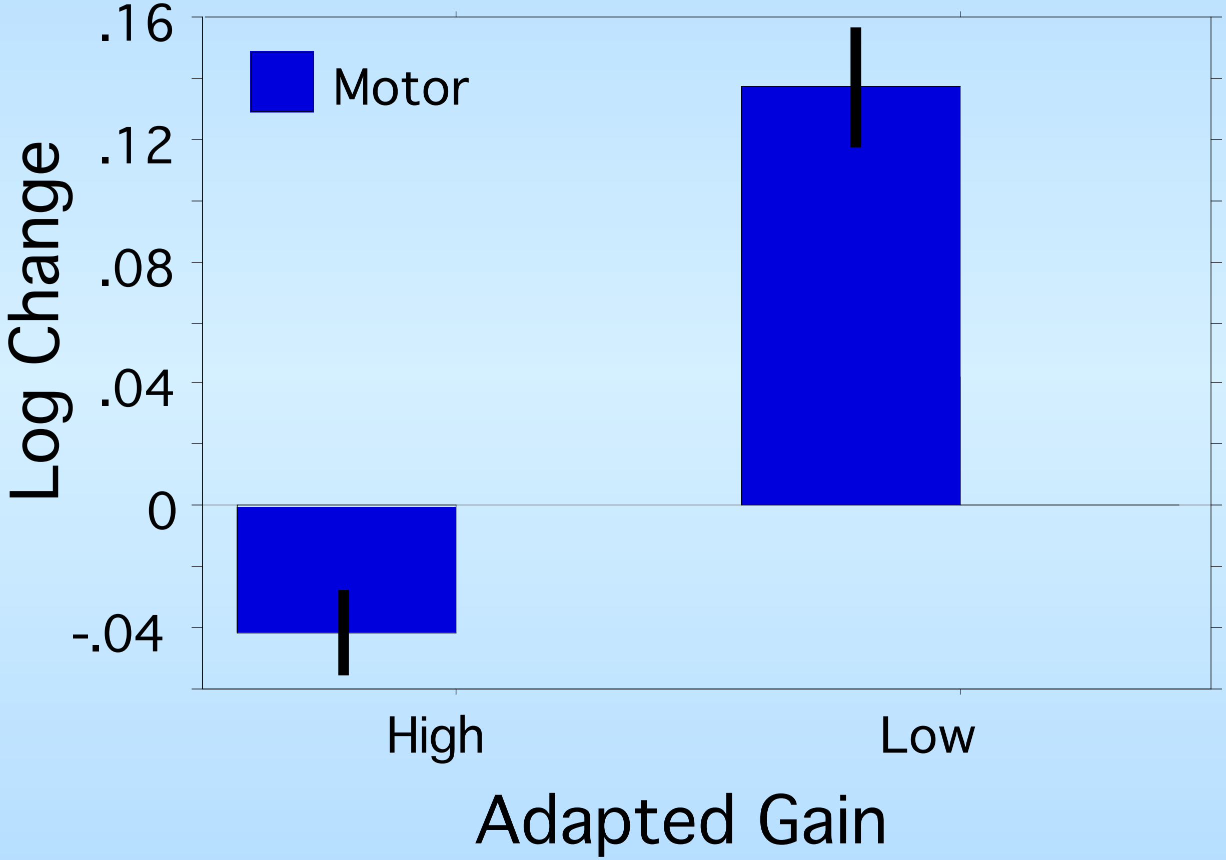
Verbal exponent: 1.39 (more than 1, $p<.005$) Lappin effect

Verbal /Motor ratio: 0.72

Also replicate accelerative distance with indoor visual estimates.

Note further that motor estimate is not similarly accelerated.

Results (post-pre)



Motor High: -10%

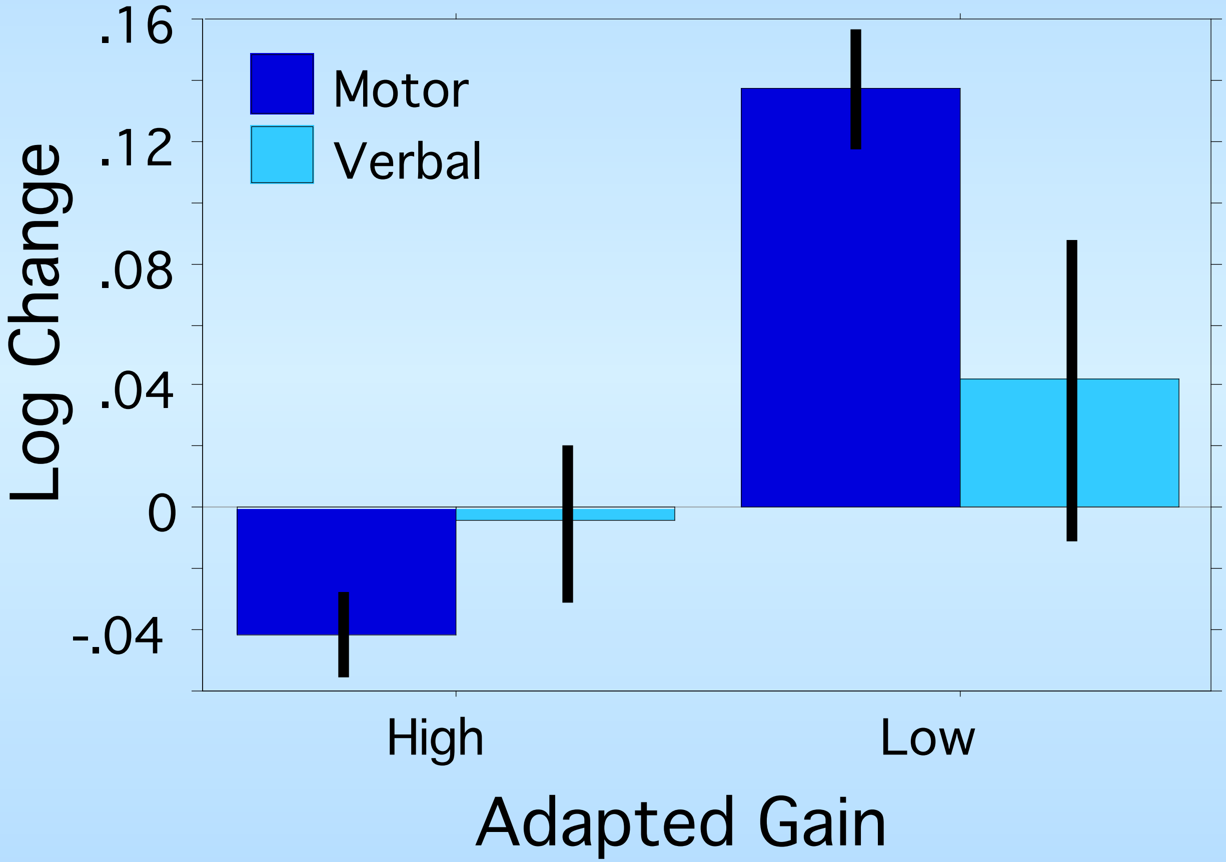
T= 3.23, p < .02

Motor Low: +35%

T=4.77, p < .01

Large reliable effects in motor task (both directions).

Results (post-pre)



Motor High: -10%

T= 3.23, $p < .02$

Motor Low: +35%

T=4.77, $p < .01$

Verbal High: N.S.

T= 0.16, $p > .20$

Verbal Low: N.S.

T= 0.84, $p > .20$

Large reliable effects in motor task (both directions).
No reliable change in verbal task.

Why the high/low asymmetry?

Assuming the pretest walking distances are an accurate reflection of perceived distance, our high gain condition (nominally a gain of 2.0) would have been about 1.3, and the low gain would have been 0.33.

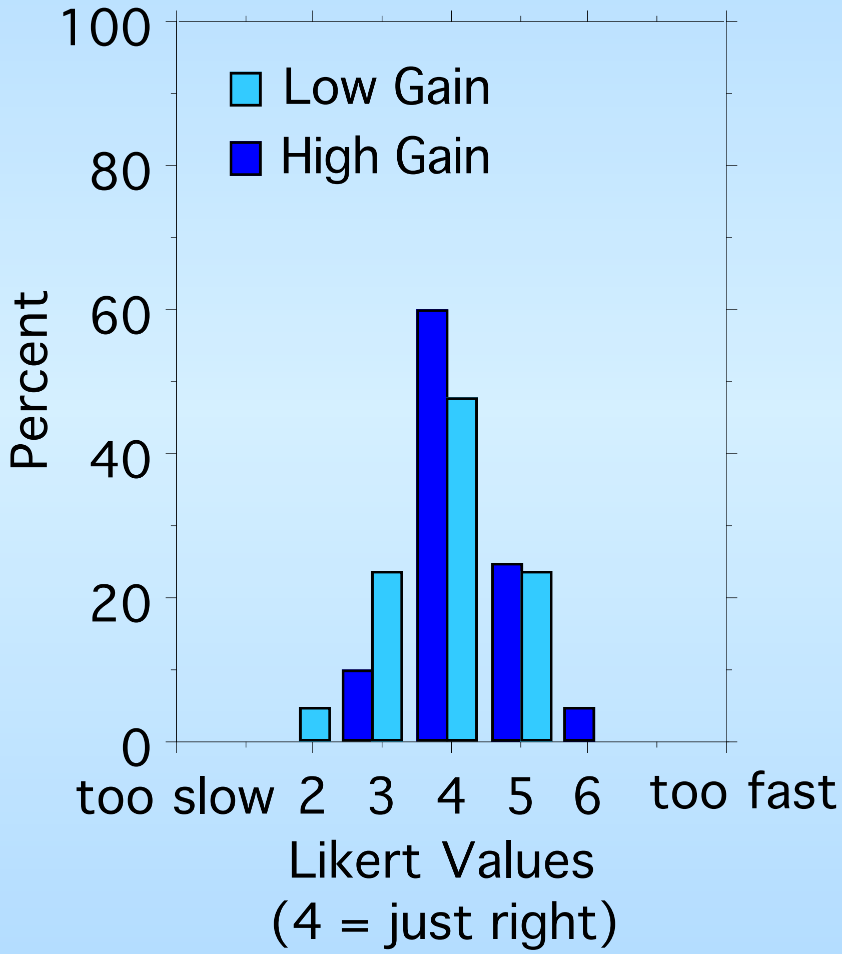
So with physical motion during adaptation we have smashed through the ceiling:

Motor Speed	Visual Speed	Time	Overshoot
4	1.34	5 min.	35%

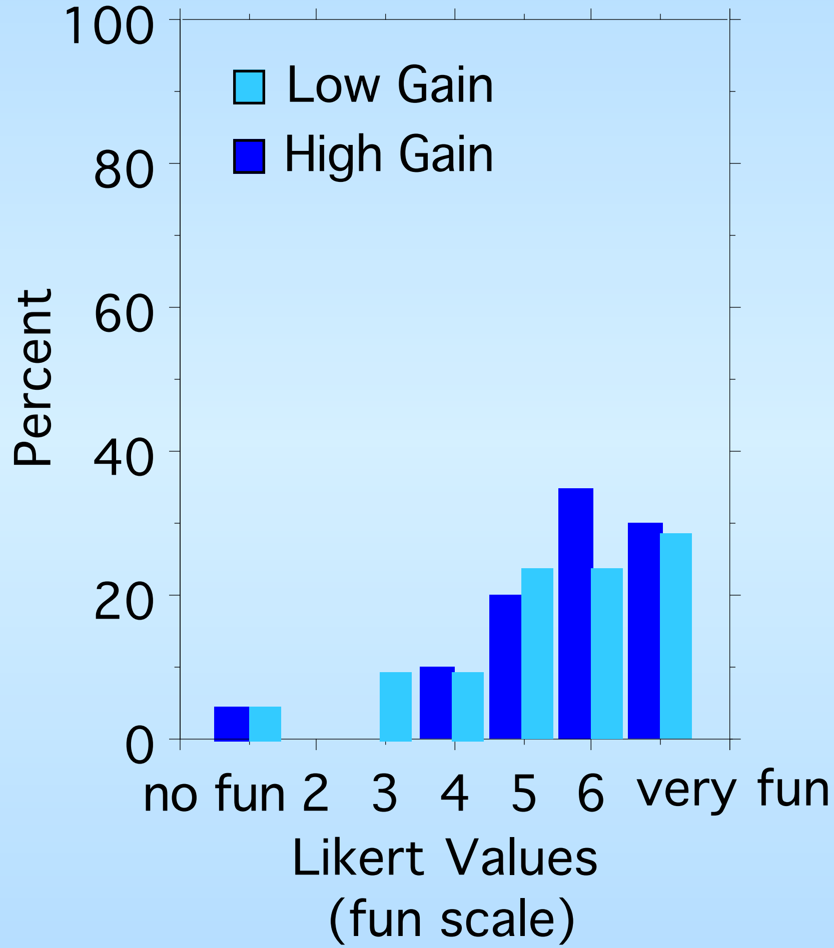
Conclusions

- The present data are consistent with a novel prediction of the multi-modal estimator model:
- Accelerations and decelerations during adaptation may play a critical role in producing stronger OVERSHOOT.
- Inertial (vestibular) signals were recalibrated in this experiment.

Little awareness of Gain Change



Lots of fun


100
80
60
40
20
0
Percent
Low Gain
High Gain
no fun
2
3
4
5
6
very fun
Likert Values
(fun scale)