

Remote Towers: Videopanorama Framerate Requirements Derived from Visual Discrimination of Deceleration During Simulated Aircraft Landing

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Knowledge for Tomorrow



DLR – NASA Cooperation 2010 within DLR RTO-Project RAiCe

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Visual Cues Experiment preparation

Steve Ellis / Advanced Displays Lab, 2010

Initial results published in:

Ellis et al., Proc. HFES 2011, pp. 71- 75

Ellis et.al, Fortschritt-Berichte VDI, Reihe 22, No. 33, 2011 pp.519-524



Overview

- **Introduction**
- 2-Alternative Decision Experiment
- Results: Response Matrix
- Discussion: FR-Dependence of Decision Errors
- Conclusion & Outlook



Virtual Tower / Remote Airport Traffic Control



Present Situation

Visual Cues
relevant for
Decision
Making



Future (Small Airports):
High resolution camera
based live video
reconstruction
of out-of-windows view

Quality of Visual Cues?



Problem:

High Resolution Digital Video Panorama $\Rightarrow$ Video Processing &
Practical Transmission Bandwidth Limit $\Rightarrow$ **max. Framerate ≈ 30 Hz**

Question:

Does low Video Framerate affect Interpretation of Visual Cues and
degrade Decision Making ?

$\Rightarrow$

Investigate Perception of Dynamic Visual Cues for Decision Making:
Experiment: Simulation of aircraft landing with decreasing roll speed

Hypothesis:

***Controller's ability to anticipate future a/c position during landing roll
could be degraded by reduced visual frame rate.***



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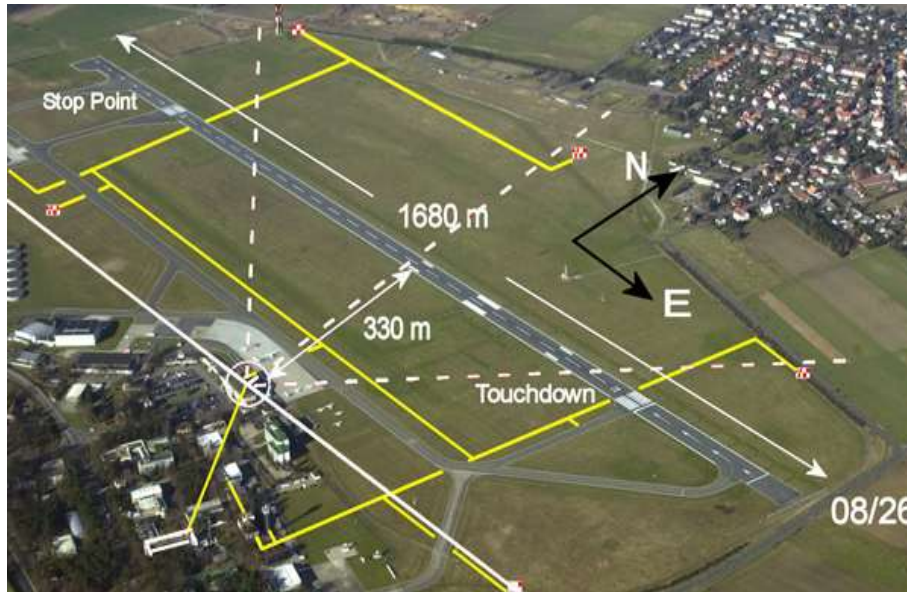


Two-Alternative (S1, S2) Decision Experiment with 13 Expert Subjects

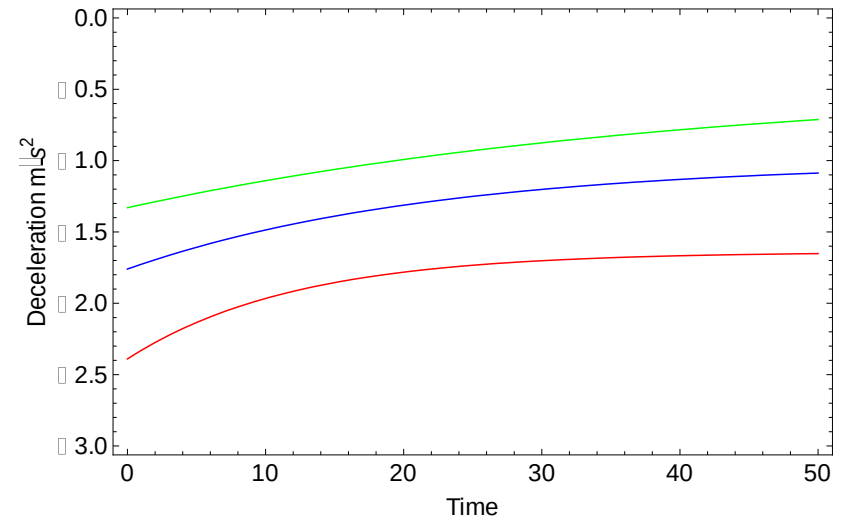
- **Task:** Decide as soon as possible if aircraft will stop before end of runway (60 A319-landings with different deceleration) with certainty level normally required for air traffic control (S2 = stop, S1 = no stop Stimulus)
- **Design:** Randomized Landings within 3 Matched Independent Groups, $n_i = 4, 4, 5$ active controllers, each group with a different video framerate
- **Training** to decision criterion: 20 landings
- **Independent variables:**
Video update rate (between groups): 6, 12, 24 Hz, after training @ 24 Hz.
A/C Deceleration (within groups): 3 realistic levels w/r high speed turnoff: nominal $a_{\max} = 1, 2, 3 \text{ m/s}^2$, randomized latin square for 60 landings / Subject
- **Dependent variables:**
Response Matrix (H, FA) $\Rightarrow$ Discriminability d' , A, Response Bias c , b , Bayes (conditional) Probabilities $\rightarrow$ Risk of Decision Error ; Decision time, Certainty



Simulated A319 Landing at Braunschweig Airport for Prediction of normal (planned Stop) vs. abnormal (Runway Overrun) Deceleration



Panorama tower demo.avi



$$\ddot{x} = -b_{min} - (b_0 - b_{min})e^{-t/\tau}$$



Pre-Experiments at NASA Advanced Displays Lab.: Adjustment of Simulation Parameters

Simul. Setup 3 x 24" HD Displays

Participants at DLR-RTO Simulator Console judging outcome of landing aircraft just after touchdown (3rd Monitor from the left):

Press spacebar at decision time

4 x (1600x1200) 21" Displays

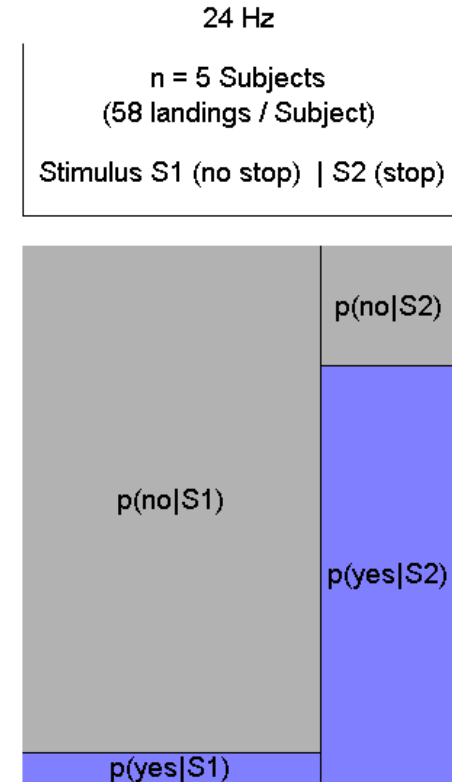
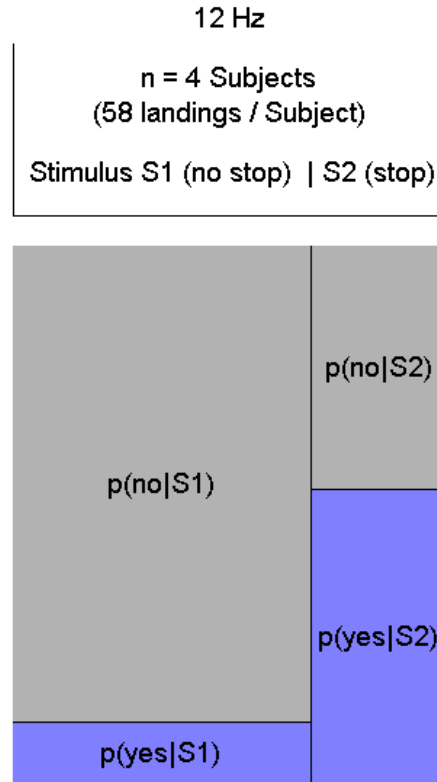
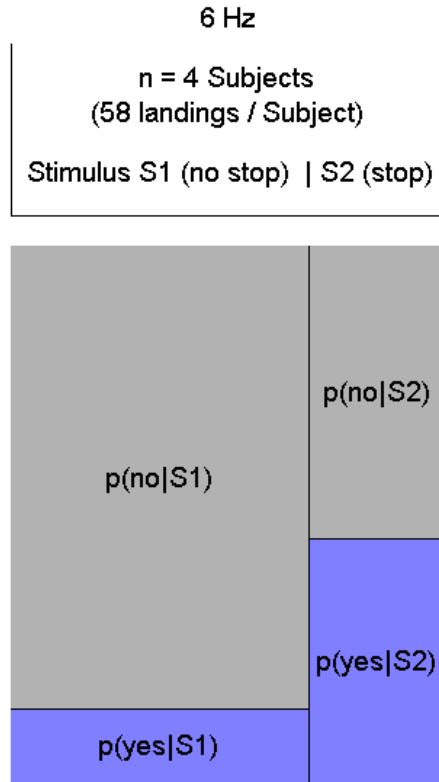


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Response Matrix: Venn Diagram & Measured Probability Estimates



Bayes
Inference
for Errors

$$p(S1|yes) = \frac{p(yes|S1)p(S1)}{p(yes)}$$

$$p(S2|no) = \frac{p(no|S2)p(S2)}{p(no)}$$



Signal Detection Theory: (H, FA) Cumulative Prob. Densities in ROC Space (Receiver Operating Characteristics)

Assumption: equal- σ Gaussian (μ , σ)

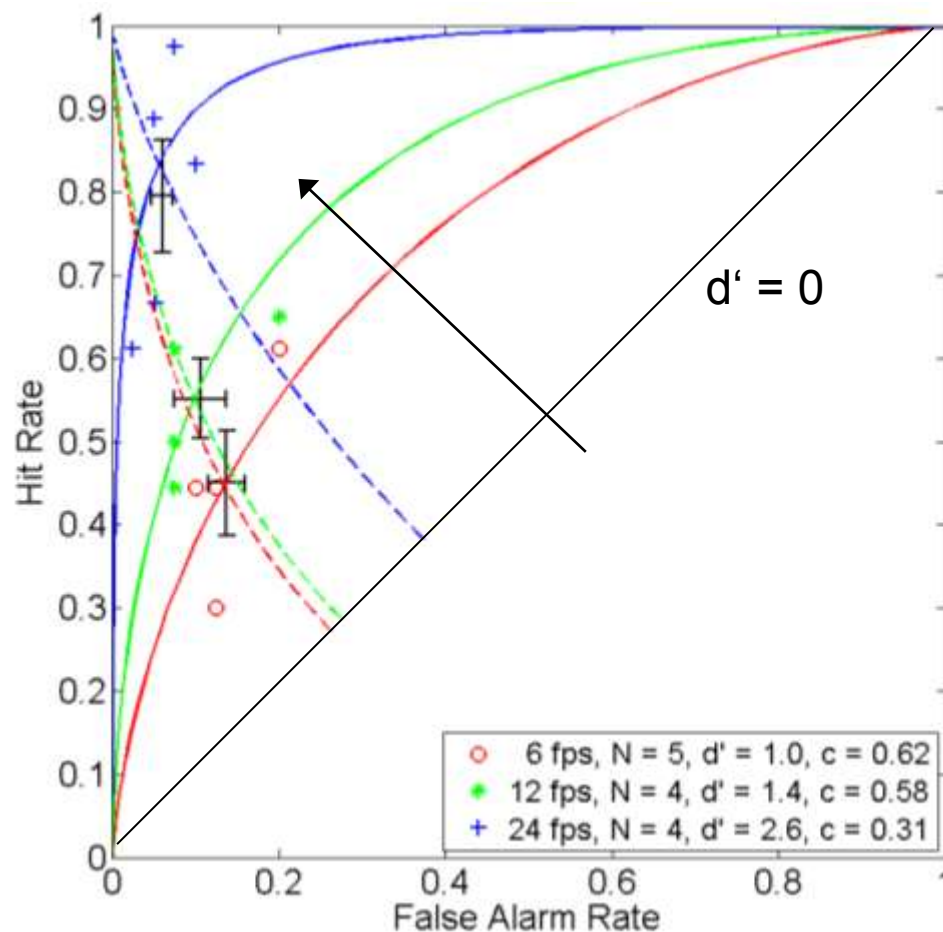
Densities for S1, S2 Response $\rightarrow$

Isosensitivity & Isobias Curves:

$$z\text{-Score } z(H) = d' + z(FA)$$

$$z(H) = -2c - z(FA)$$

$\Rightarrow$ **Discriminability d'** = $\mu_2 - \mu_1$
independent of Decision **Criterion c**



$\Rightarrow$ Choose **Nonparametric Discriminability A** (= area under ROC curve) & **Bias b**
without equal variance Gaussian condition



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Derive Minimum Framerate Requirement via Bayes Inference:

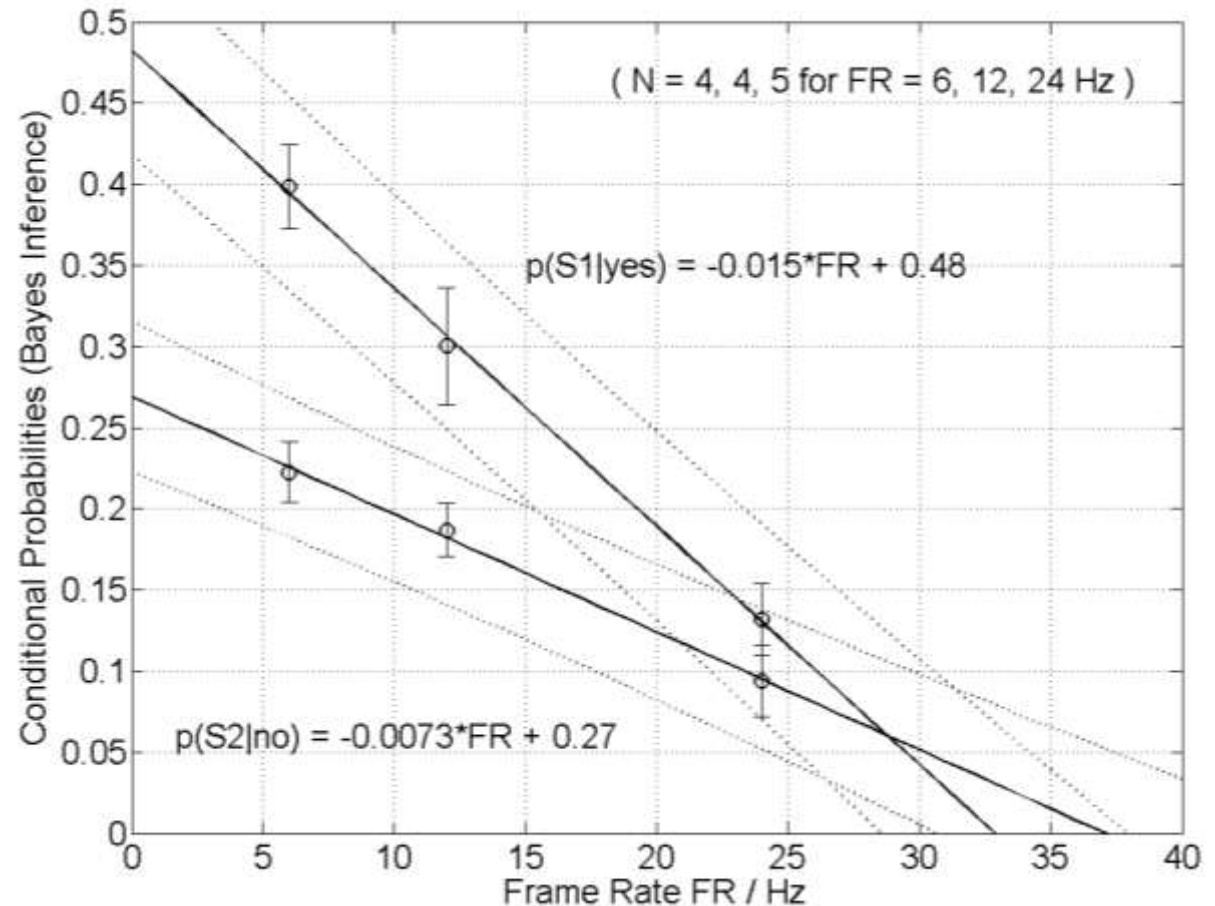
Minimize „Risk“ for
unexpected stimulus



Decision error Probabil.:

S_i contrary to prediction:

$p(\text{unexpected } S_i | \text{response})$



Non-Parametric Discriminability Index A, Response Bias b

[Mueller & Zhang 2005]

Discriminability: average area under all proper ROC curves

$$A = \begin{cases} \frac{3}{4} + \frac{H - FA}{4} - FA(1 - H) & \text{if } FA \leq 0.5 \leq H \\ \frac{3}{4} + \frac{H - FA}{4} - \frac{FA}{4H} & \text{if } FA \leq H \leq 0.5 \\ \frac{3}{4} + \frac{H - FA}{4} - \frac{1 - H}{4(1 - FA)} & \text{if } 0.5 < FA \leq H \end{cases}$$

No Gaussian Response probability distribution of Stimulus S1-, S2- familiarity or certainty rating required

Response Bias/criterion:

$$b = \begin{cases} \frac{5 - 4H}{1 + 4FA} & \text{if } FA \leq 0.5 \leq H \\ \frac{H^2 + H}{H^2 + FA} & \text{if } FA \leq H < 0.5 \\ \frac{(1 - FA)^2 + (1 - H)}{(1 - FA)^2 + (1 - FA)} & \text{if } 0.5 < FA \leq H \end{cases}$$

→ A, b, calculated directly from Response Matrix



Discriminability A Bias (Criterion) b

Isosensitivity Curves

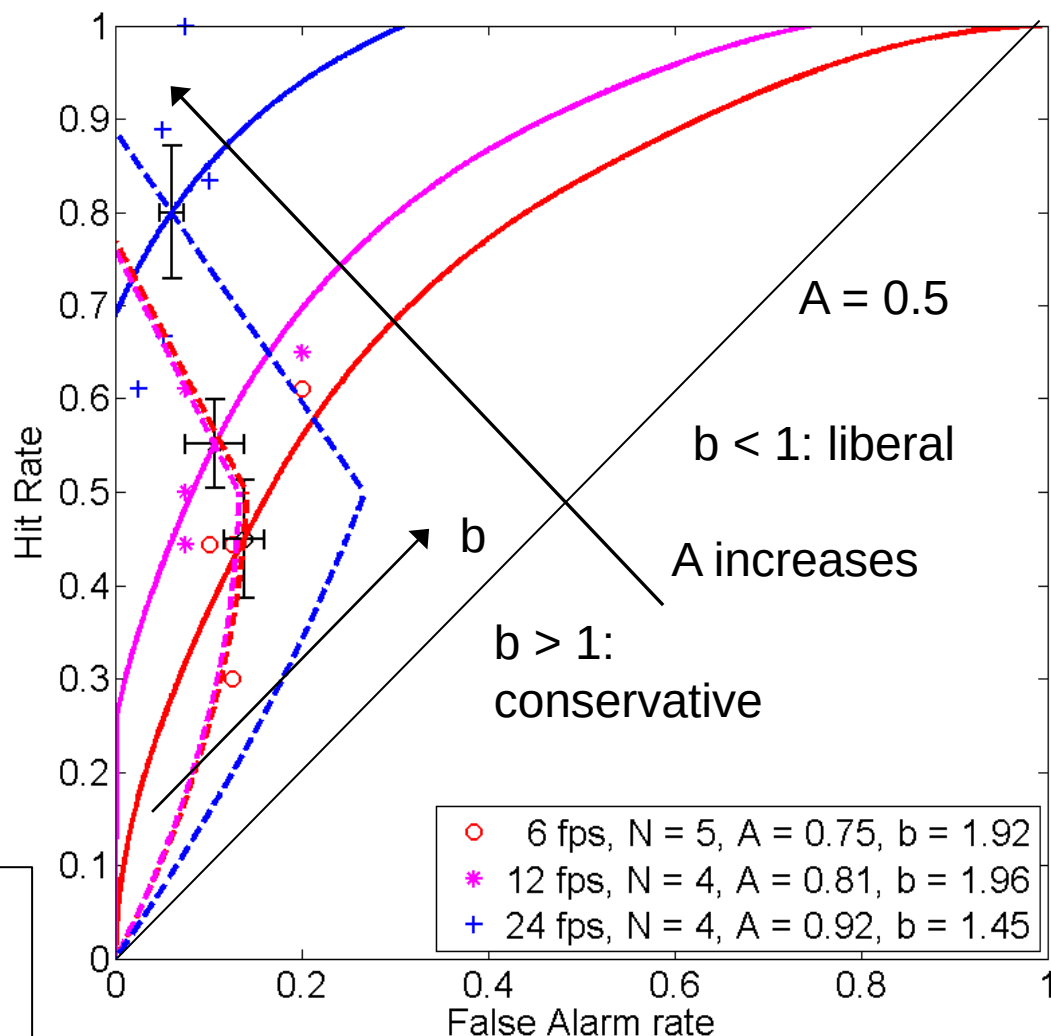
A = average area under all proper ROC curves = 0.5 - 1

Isobias Curves

b = ROC slope = dH/dF
= Likelihood Ratio

with increasing Framerate:

Discriminability A increases
Criterion b decreases: more liberal

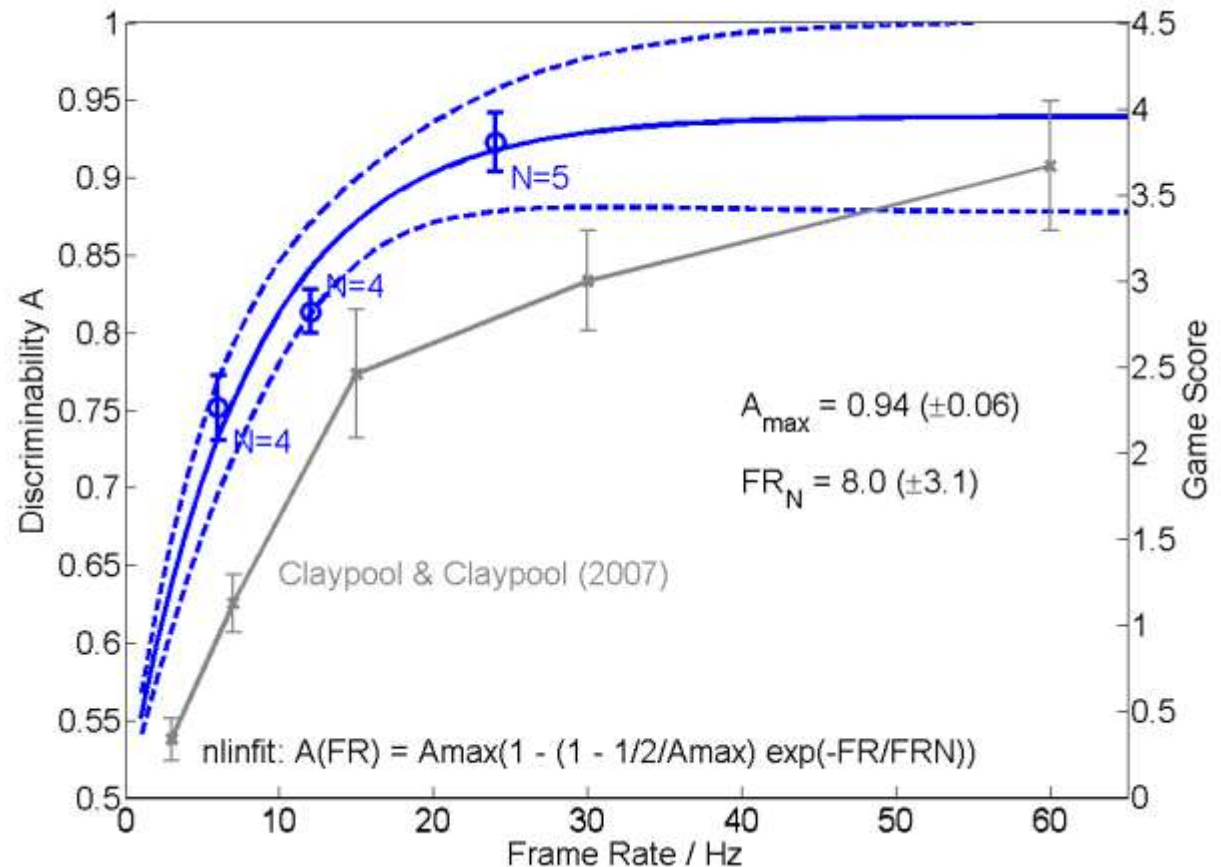


Discriminability (Sensitivity) Index A vs Video Framerate $FR = 1 / T$ compared with [Claypool 2007] Shooter Game Score

Hypothesis for Model Fit:

Asymptotic decrease of FR-
Effect due to decreasing
sample & hold delays T in
visual short term memory

$$\sim (1 - \exp(-k / T))$$



Conclusion & Outlook

- Hypothesis (Predictability of future A/C Position increases with FR) supported by experimental Results
- Bayes Inference & A-Extrapolation indicate minimum Video Framerate ≈ 35 Hz required for minimizing decision errors
- Response Bias $b < 1$ towards conservative decisions (= avoiding False Alarms), decreases with increasing framerate $\Rightarrow$ Errors decrease, Subjects more confident.
- Additional measurements > 24 Hz and theoretical model required for confirming minimum framerate and for supporting vis. Short-term memory hypothesis
- Suitably Designed Decision Experiments (Simulations & Field Tests) allow for Quantification of RTO Specifications, Performance and Risk by means of Bayes Inference and Detection Theory
 $\rightarrow$ preliminary results with RTO shadow mode tests $\rightarrow$ RAiCe Project workshop



Acknowledgement

For help in preparing and performing this experiment we are indebted to the DLR Remote Tower Team and the Tower Simulator Staff, in particular

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and M. Friedrich

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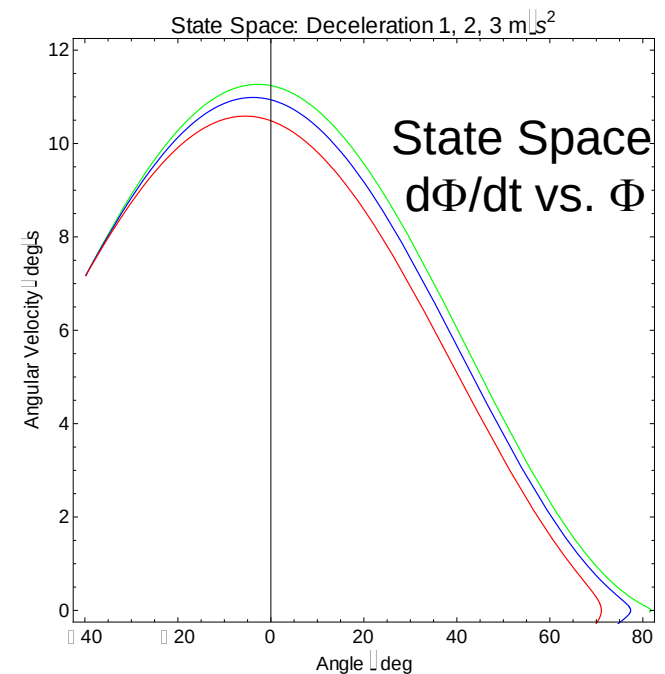
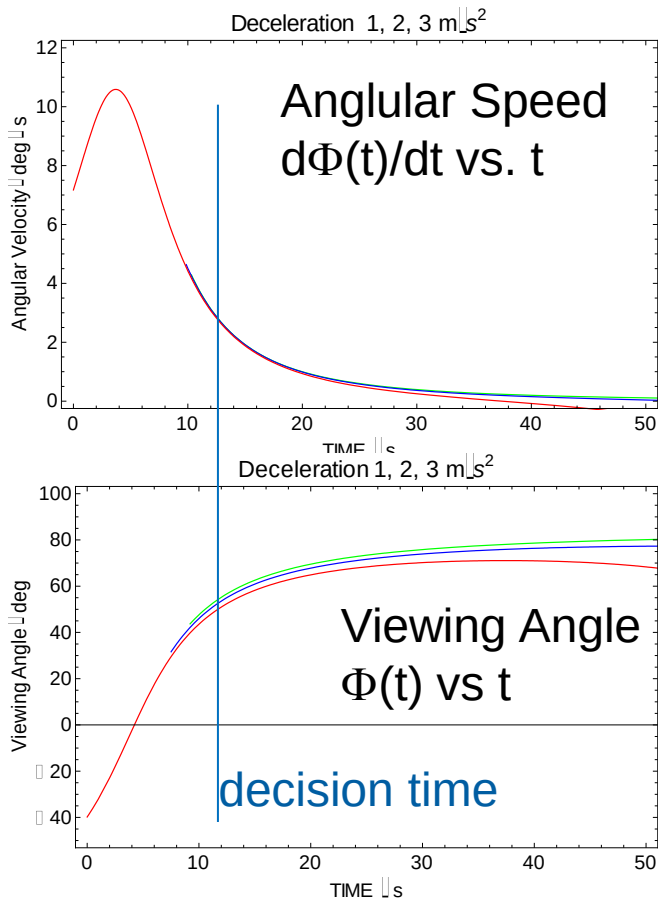
Backup Slides



Discriminability A ~ FR: Effect of **Visual Working Memory** ?...

Sampling of Evidence for Discrimination: viewing angle(t), angular speed(t)?

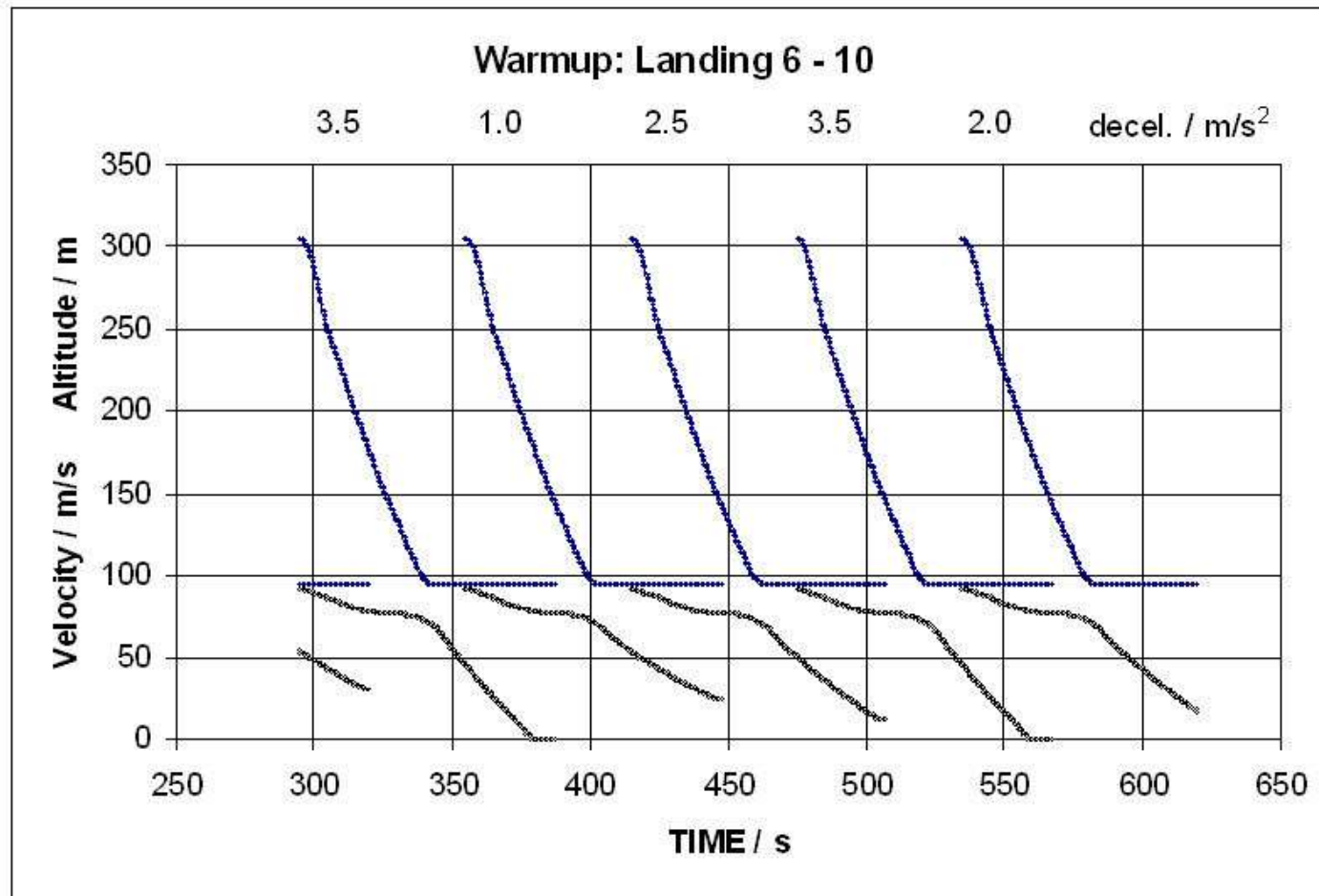
Simulation of Movement / Observation Dynamics $\ddot{x} = -b_{min} - (b_0 - b_{min})e^{-t/\tau}$



...or Heuristics of trained Expert ?



Landing Dynamics: Simulator Logged Data



Response Matrix: Group Averages for 60 Landings / Subject

Alternative
Independent
Events

S1 = no-stop

S2 = stop.

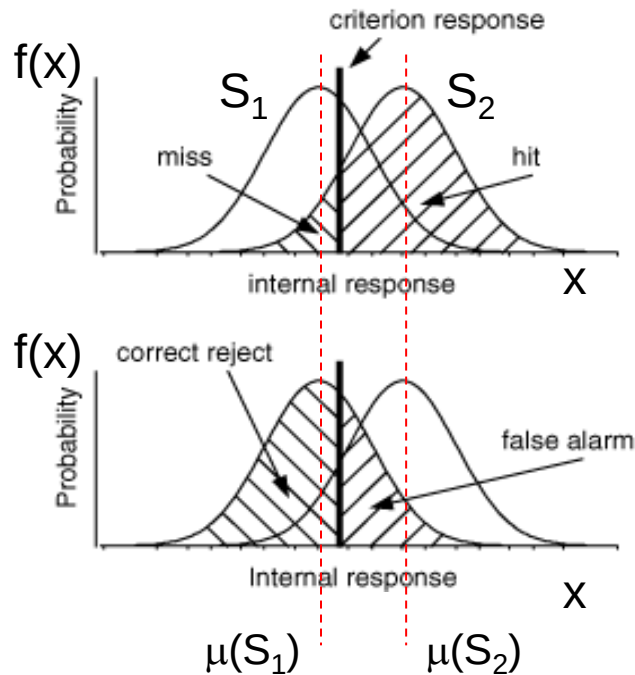
S1: Deceleration
< critical braking →

S2: Deceleration
≥ critical braking →

Alternative Stimuli	Response for 3 Video Framerates: Probability Estimates				
	No-stop predicted			Stop predicted	
Low Deceleration No-stop Stimulus S1	$p(\text{no} S1)$ = Correct Rejection	6 Hz	0.86 (0.02)	$p(\text{yes} S1)$ = False Alarm	0.14 (0.02)
		12 Hz	0.89 (0.03)		0.11 (0.03)
		24 Hz	0.94 (0.01)		0.06 (0.01)
High Deceleration Stop Stimulus S2	$p(\text{no} S2)$ = Misses	6 Hz	0.55 (0.06)	$p(\text{yes} S2)$ = Hit	0.45 (0.06)
		12 Hz	0.45 (0.05)		0.55 (0.05)
		24 Hz	0.22 (0.07)		0.78 (0.07)

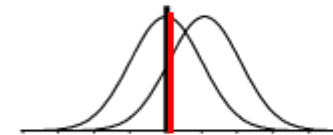


Signal Detection Theory: independent Gaussian Densities (μ , σ) assumed for Internal Response to S_2 (=Landing with Stop) and S_1 (= RWY Overrun)



liberal

Hits = 97.5%
False alarms = 84%



Hits = 84%
False alarms = 50%



Hits = 50%
False alarms = 16%

conservative

Criterion **c**

Discriminability Index

$$d' = \mu(S_2) - \mu(S_1)$$

$$= \Phi^{-1}(\text{Hit Rate}) - \Phi^{-1}(\text{FA-Rate}) = z(H) - z(FA)$$

For equal variance: d' independent of

decision bias / response criterion: $c = - (z(H) + z(FA)) / 2$

