Speed-related auditory feedback from an electric vehicle on the braking behavior in a 3D-driving simulator

Perceptual and Motor Processes in Driving Assessment and Design II / AHFE 2012

Bringoux[1] L, Morice[1] AH, Sciabica[2] JF, Goulon[1] C, Besson[1] P, Bourdin[1] C, Dousset[1] E, Marqueste[1] T, Martha[1] C, & Roussarie[2] V

[1]Institute of Movement Sciences - Aix-Marseille University and CNRS

[2]PSA Peugeot-Citroën

Speed choice and driving safety

Drivers' choice of speed: predictor of crash risk

- Roadside observation (Wasielewski, 1984)
- Self-report (French et al., 1993)
- Simulation (Horswill & McKenna, 1999)

Speed choice and electric vehicles

Optimistic projections:

"Because drivers may try to conserve battery power, they would not push their car and may tend to stay well within the speed limit"

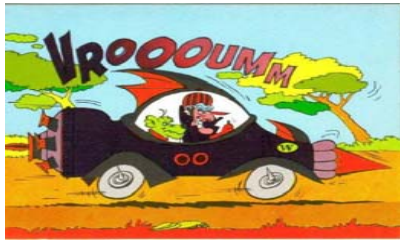
"The unintended benefit could be one of improved safety, bringing down driving speeds"

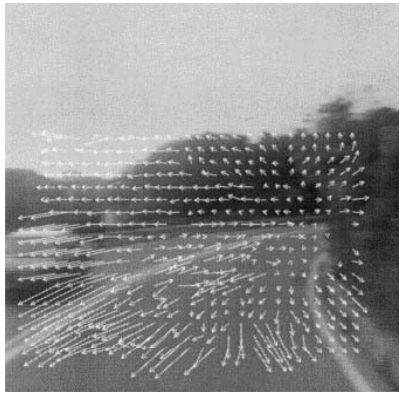
⚠ What about speed perception when driving???

Speed choice and speed perception

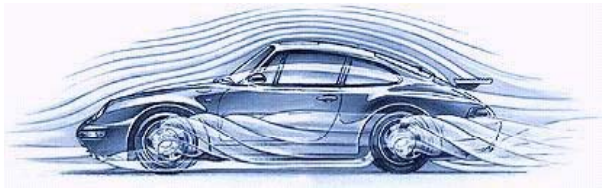
Drivers' choice of speed depends on:

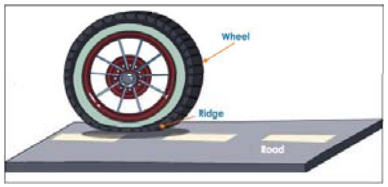
- Personality traits (Delhomme et al., 2009)
- Perceived actual speed (Horswill & McKenna, 1999)





Visual cues

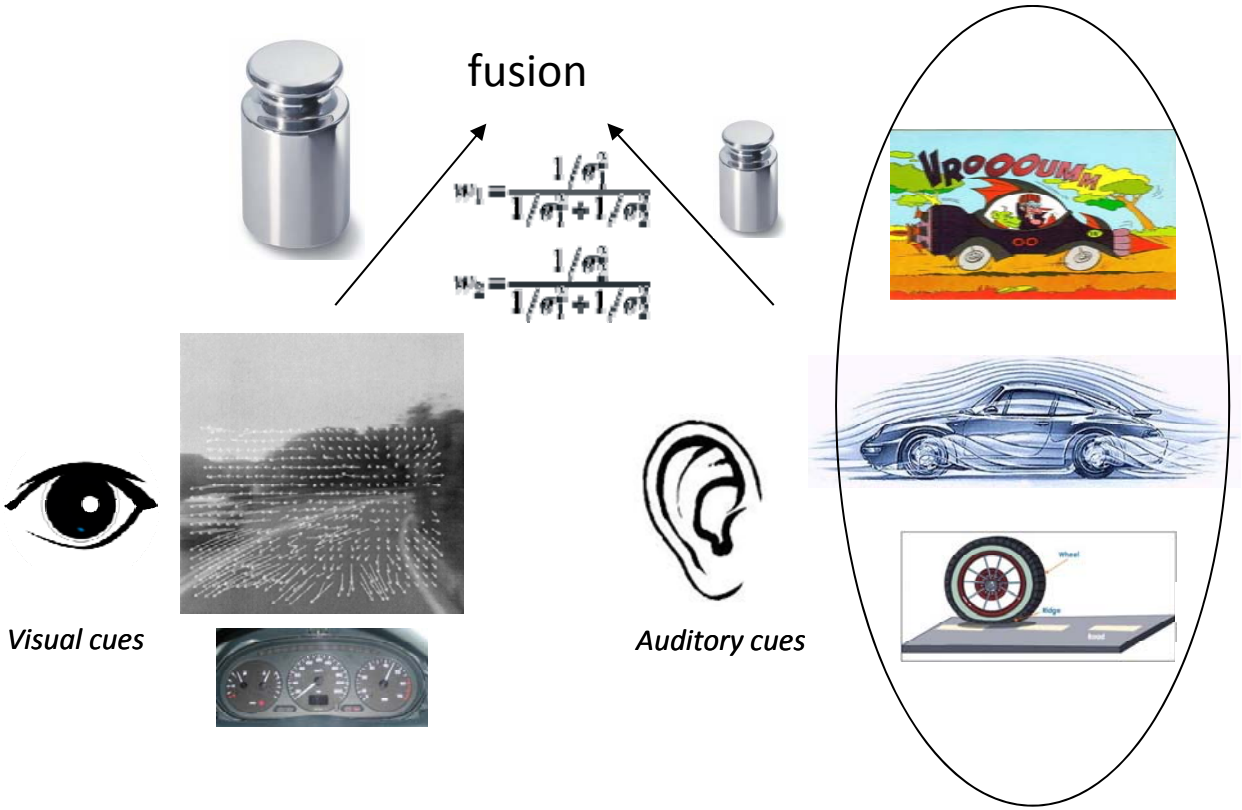




Auditory cues

Speed choice and speed perception

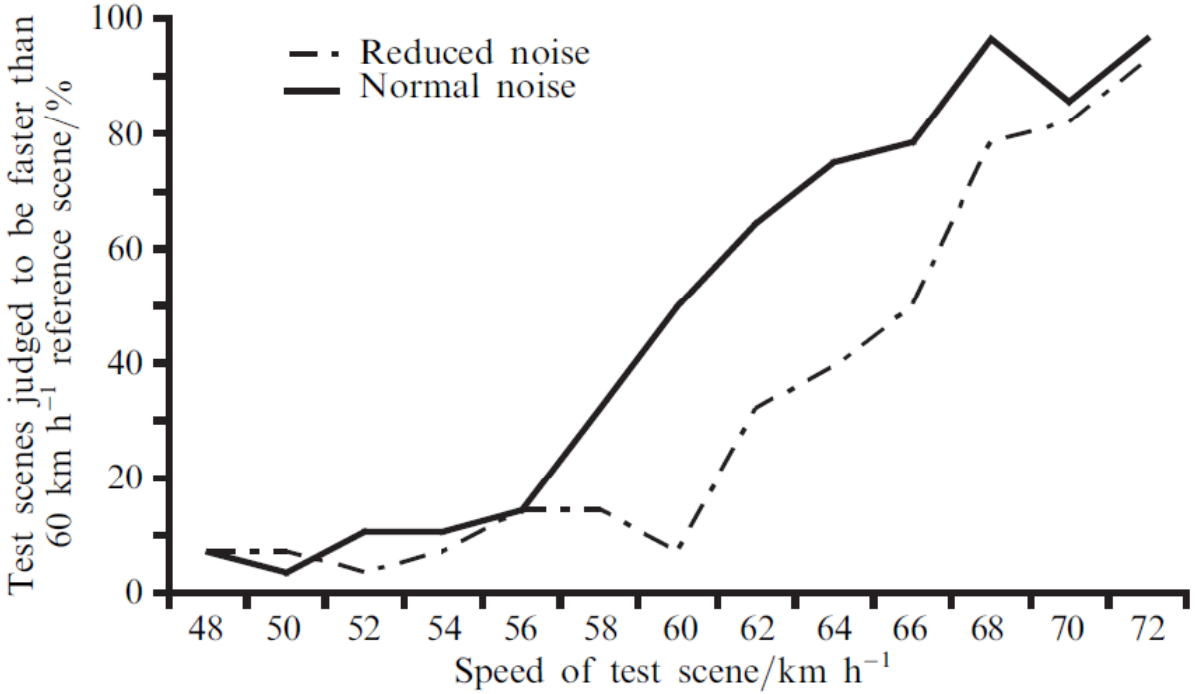
Speed perception arising from multisensory integration



- Internal car noise crucial for speed visual judgements (Horswill & Plooy, 2008a)

Speed choice and speed perception

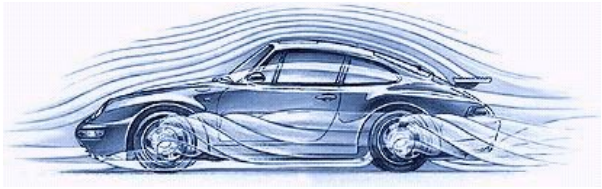
(Horswill & Plooy, 2008a)

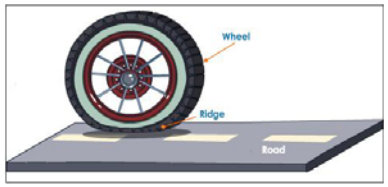


- The reduction in noice led to participants judging speeds to be significantly slower

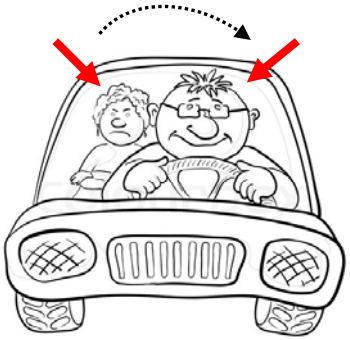
Remaining questions

- Sound relevance for speed perception in electric cars?





- Direct transfer from speed perception to driving behavior?



Purpose of the study

Audiovisual integration on driving behavior

- Speed-related auditory feedback from an electric car in a 3D-driving simulator
- Speed-related effects investigated on braking

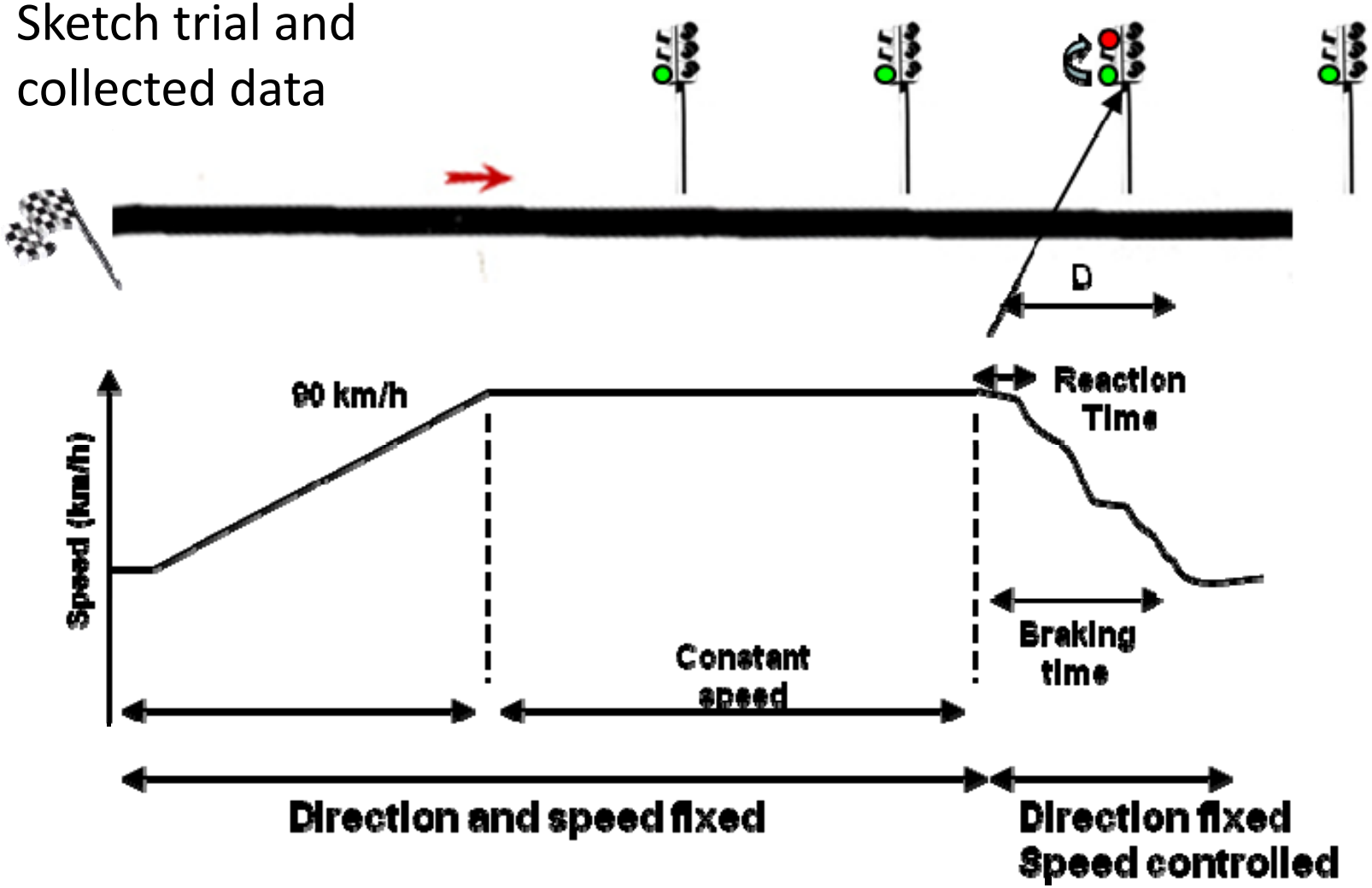
Main hypotheses

- Lower auditory gain ➲ speed understimation ➲ delayed and abrupt braking
- Enhanced influence when speed-related visual cues are poor

3D-driving simulator


www.fraps.com

Sketch trial and collected data



Visual Scene 1 (poor optic flow)
speed 90 km/h

12 participants
(driving licence > 2y)

Visual Scene 2 (Rich optic flow)
speed 90 km/h

Stopping Distance 1
40 m

Stopping Distance 2
80 m

Stopping Distance 1
40 m

Stopping Distance 2
80 m

Auditory Gain
Referred to visual kinematiks:
+20%
+10%
90 km.h^{-1}
-10%
-20%
X 3 repetitions

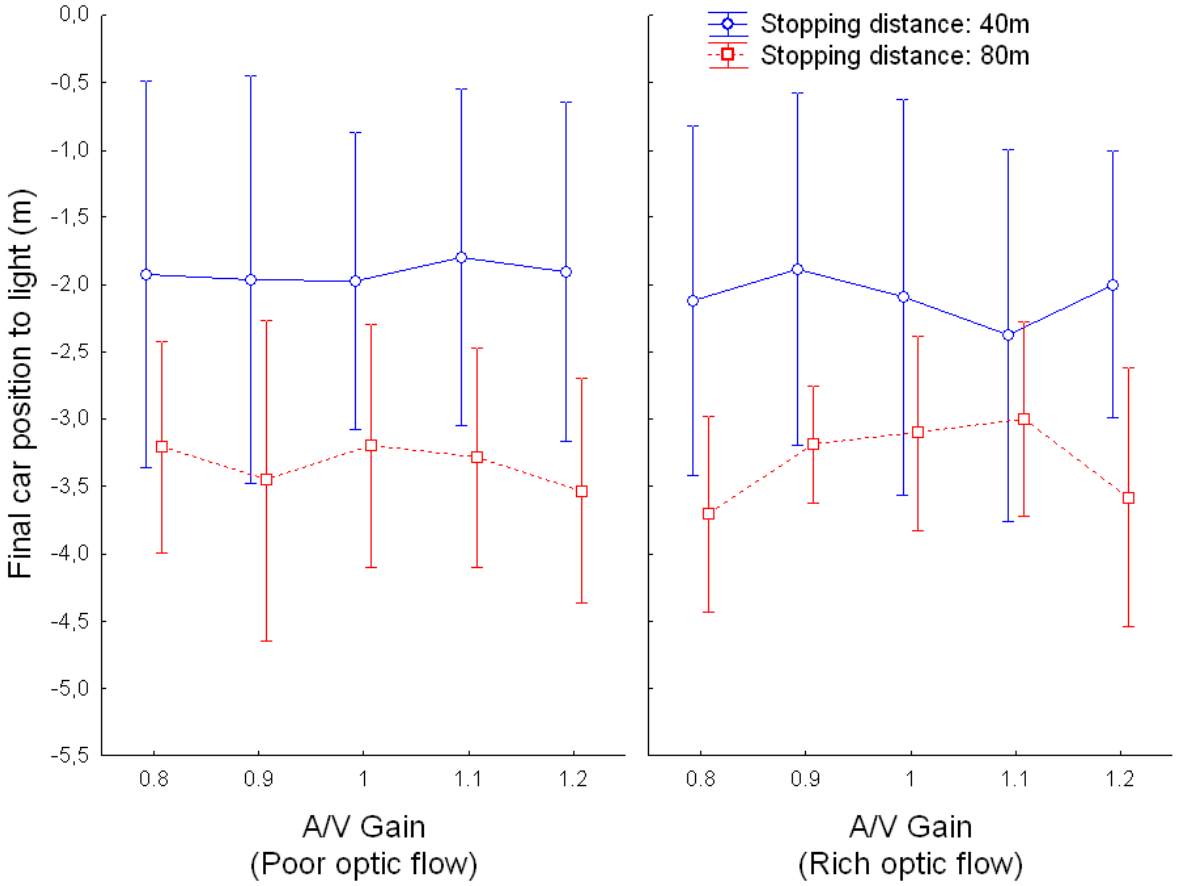
Auditory Gain
Referred to visual kinematics
+20%
+10%
90 km.h^{-1}
-10%
-20%
X 3 repetitions

Auditory Gain
Referred to visual kinematics
+20%
+10%
90 km.h^{-1}
-10%
-20%
X 3 repetitions

Auditory Gain
Reffered to visual kinematics
+20%
+10%
90 km.h^{-1}
-10%
-20%
X 3 repetitions

→ **Exp Plan: 2 Vis_S x 2 Stp_D x 5 Audit_G x 3 r**

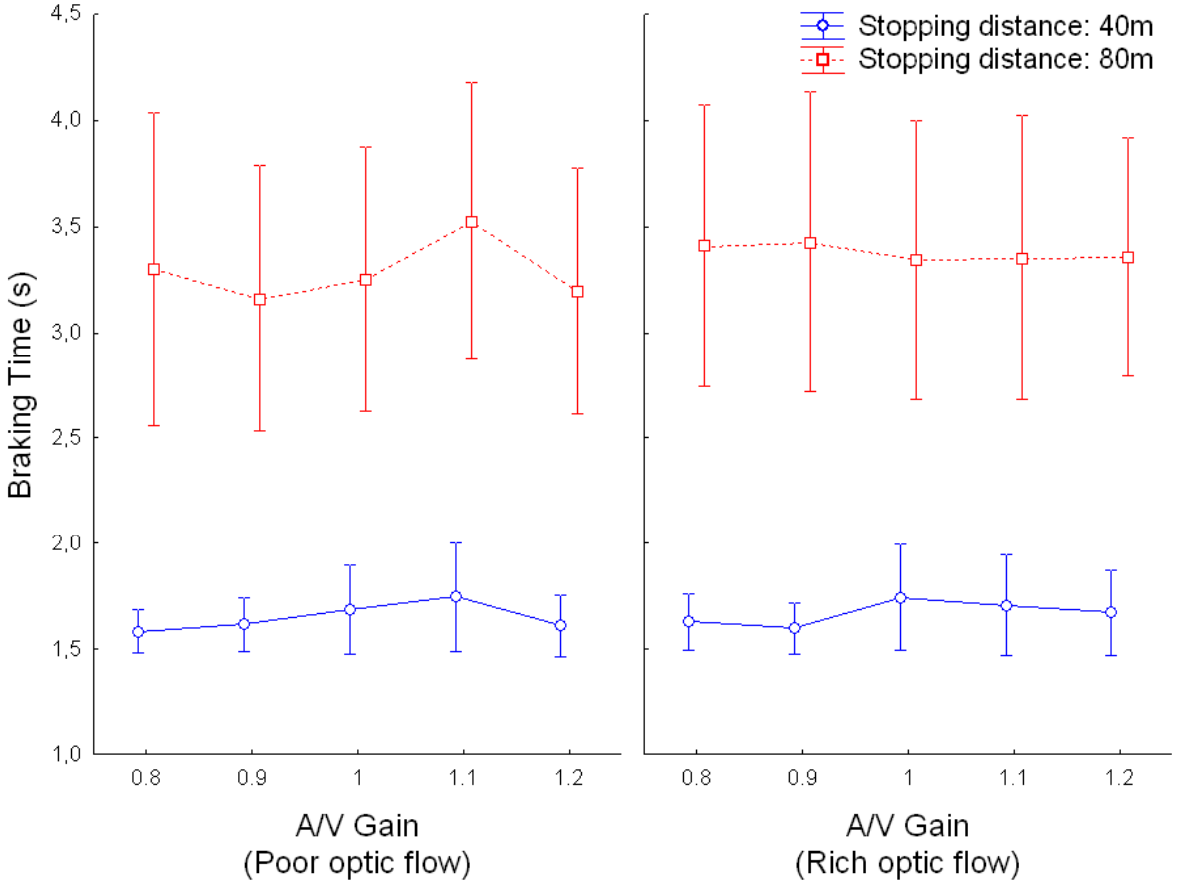
Final car position



- The shorter the stopping distance, the further the final car position (i.e., closer to the light as drivers stopped before the target on average)

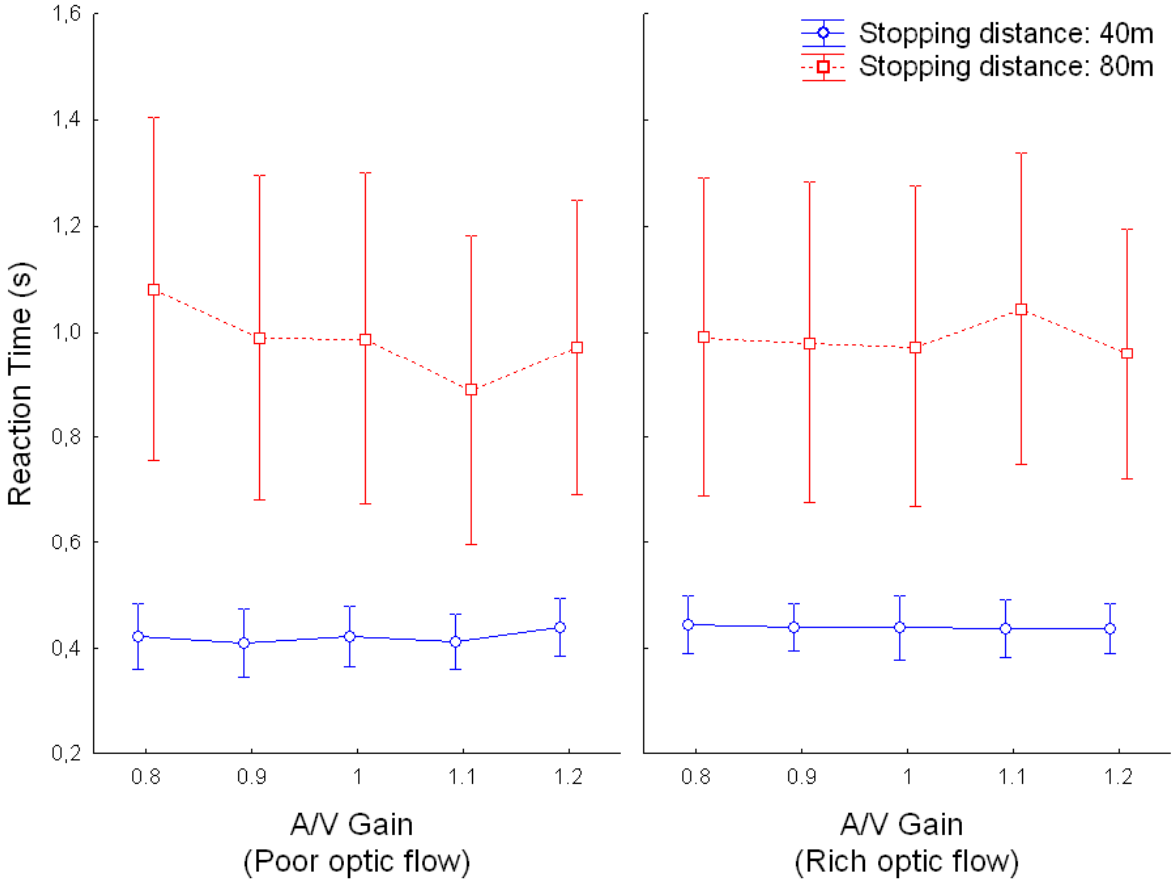
- Neither main effects of the visual scene and the auditory gain nor interactions between these factors

Braking time



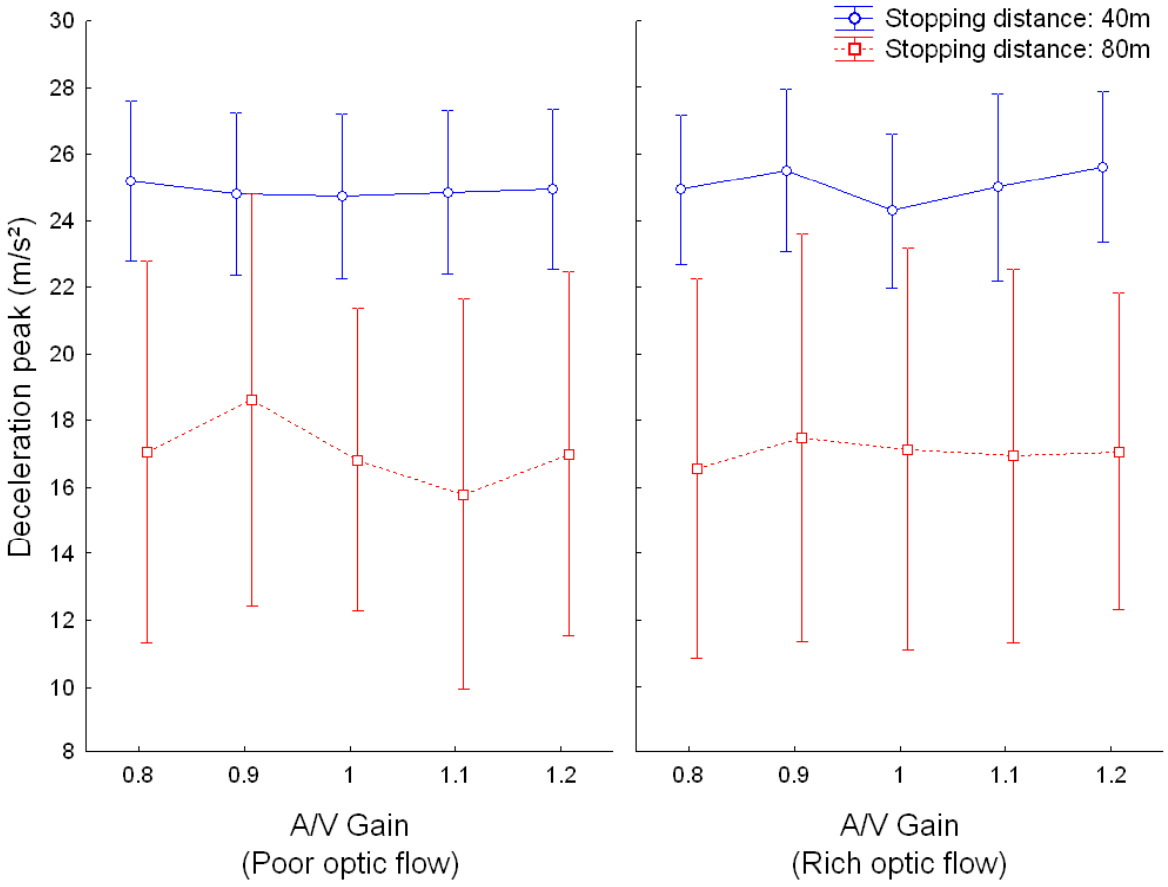
- The shorter the stopping distance, the shorter the braking time
- Greater variability for the longer stopping distance
- Neither main effects of the visual scene and the auditory gain nor interactions between these factors

Reaction time



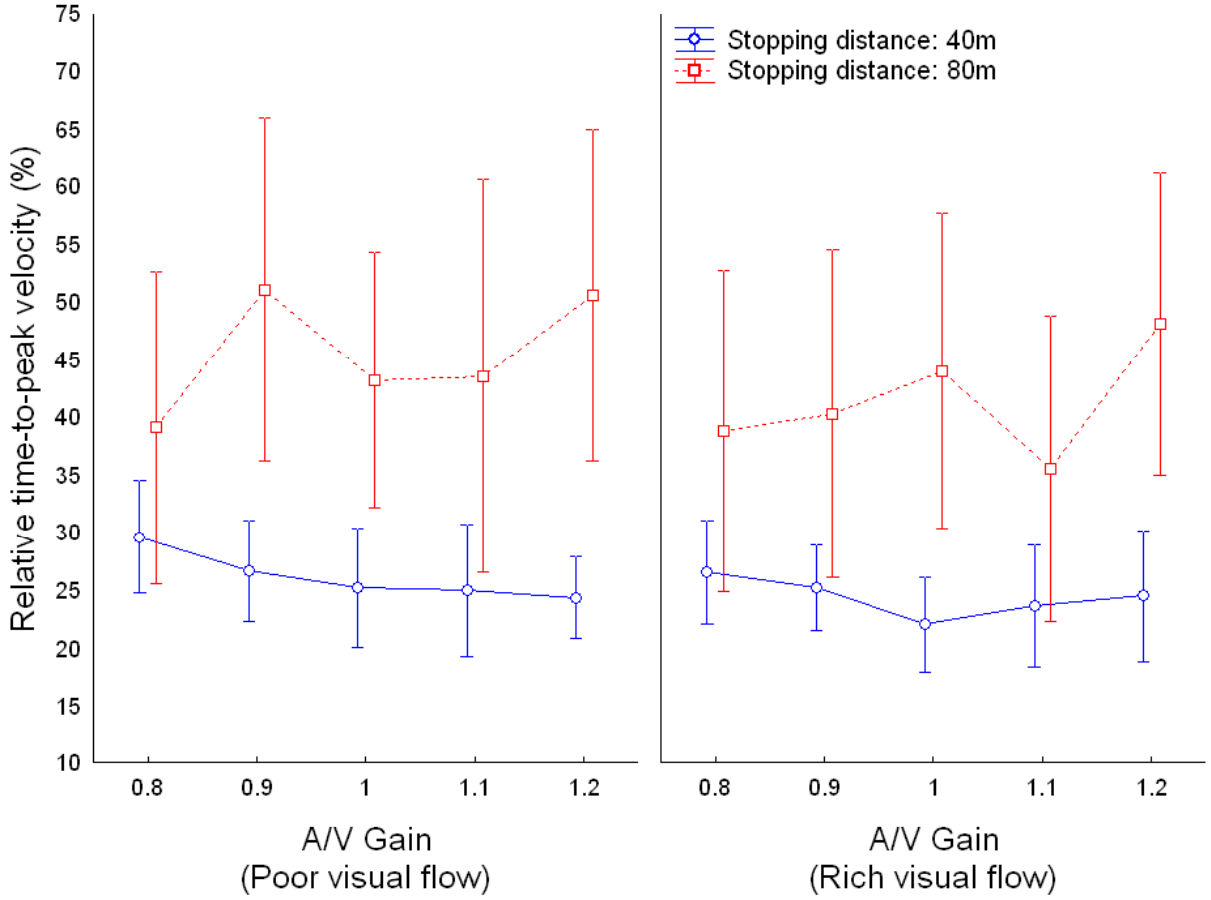
- The shorter the stopping distance, the shorter the reaction time to brake
- Greater RT variability for the longer stopping distance
- Neither main effects of the visual scene and the auditory gain nor interactions between these factors

Deceleration peak



- The shorter the stopping distance, the higher the deceleration peak
- Greater variability for the longer stopping distance
- Neither main effects of the visual scene and the auditory gain nor interactions between these factors

Brake pedal's relative time-to-peak velocity (!)



- The shorter the stopping distance, the shorter the pedal's relative time-to-peak velocity
- Greater variability for the longer stopping distance
- Neither main effects of the visual scene and the auditory gain nor interactions between these factors

No significant effect of sound manipulation… Why?

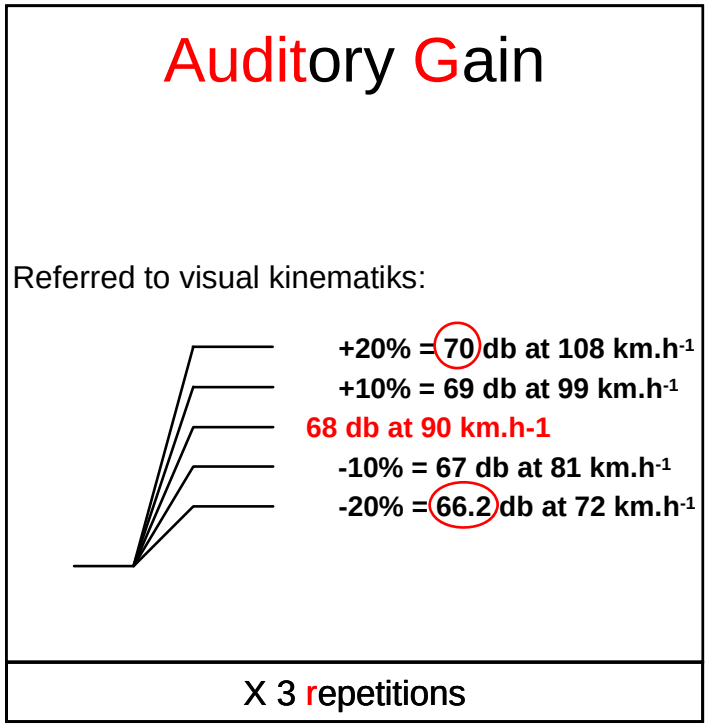
H1 Speed-related **visual cues** are informative enough


- Both ’‘rich’' and ’'poor’' optic flow conditions convey relevant information about speed and are not sufficiently discriminant


- Extremely poor optic flow (e.g., fog or night) needed in 3D-space for the sound to become relevant (Horswill et Plooy, 2008b; Pretto, Bresciani, & Bülthoff, 2010)?

No significant effect of sound manipulation… Why?

H2 The tested range of **sound levels** is too small

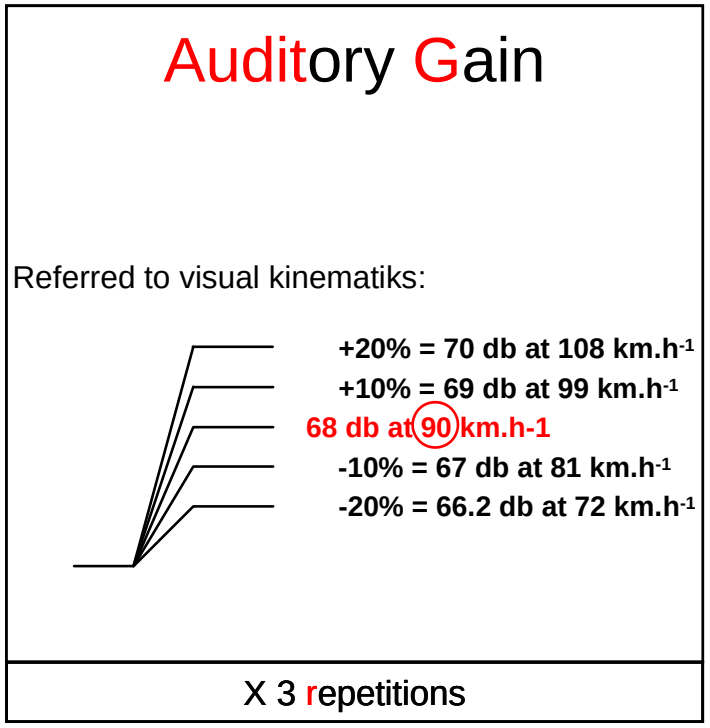


- Less than 4 dB
  vs 5 db in Horswill & Plooy (2008a)

- Larger intensity range (> 4 dB) for the sound to become discriminant for speed perception in electric cars?

No significant effect of sound manipulation… Why?

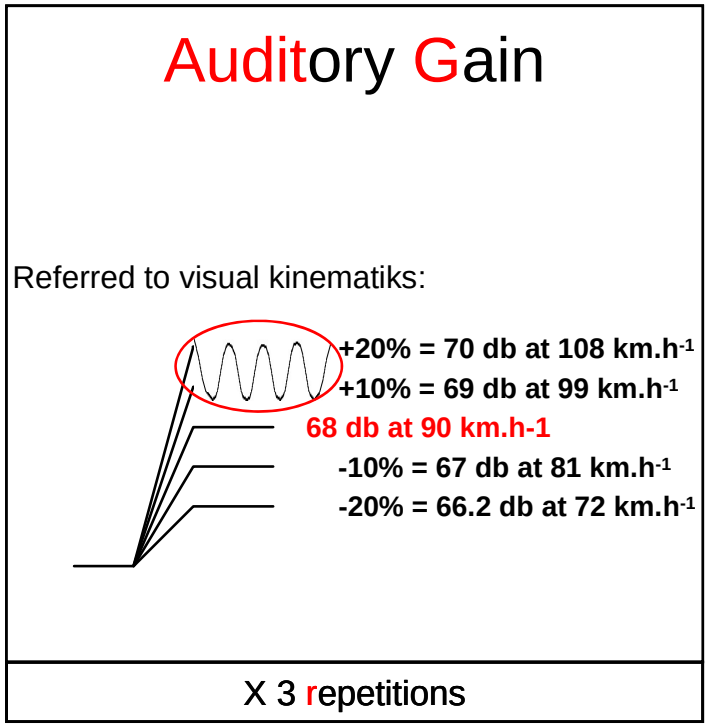
H3 The speed-related sound from an electric car becomes relevant at **higher speeds**



- Different Sound Frequency Spectra between combustion and electric cars (Kim et al., 2012)
- May auditory meaningful cues for speed perception be speed- and frequency-dependent?

No significant effect of sound manipulation… Why?

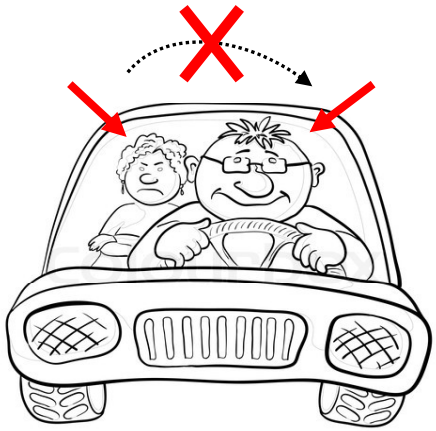
H4 The speed-related sound from an electric car becomes informative **when it varies**



- The constant speed before braking may decrease the sound relevance for speed perception
- Refresh inputs for multisensory integration (Bringoux et al., 2009)
- Auditory cues ➲ speed perception or change in speed perception?

No significant effect of sound manipulation… Why?

H5 **No transfer** from speed perception to driving control



- Mismatch between perceptual states and sensorimotor control (e.g., Bringoux et al., 2012)
- Nine on the 12 participants explicitely declared having noticed a manipulation of speed across trials
- Speed perception vs speed control?

Conclusion: speed-related sound and electric car issues

Ongoing and future studies on:

- Audio-visual interactions
- Sound structure
- Sound dynamics

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Thank you for your attention!

lionel.bringoux@univ-amu.fr

EXTRA SLIDES

Pretto, Bresciani, & Bülthoff (2010)

Reduced luminance=increases perceived speed=decreases driving speed

Speed was underestimated with distance-independent contrast reduction but overestimated with distance-dependent contrast reduction

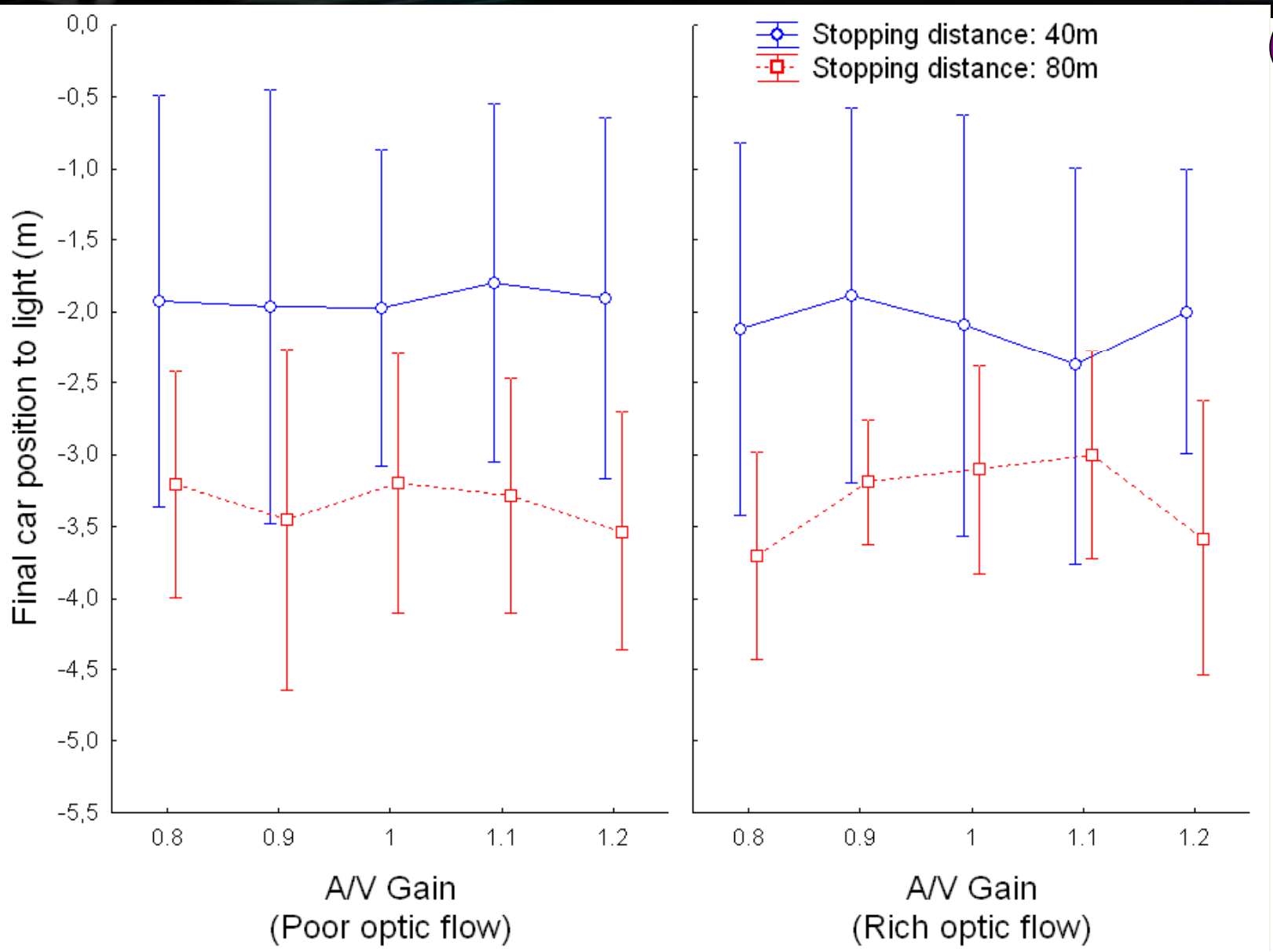
Participants increased speed with distance-independent contrast reduction but decreased speed with distance-dependent contrast reduction.

Development of auditory concept of car speed is gradual and initially favors sound level explanation (Gatehouse & Frankie, 1980).

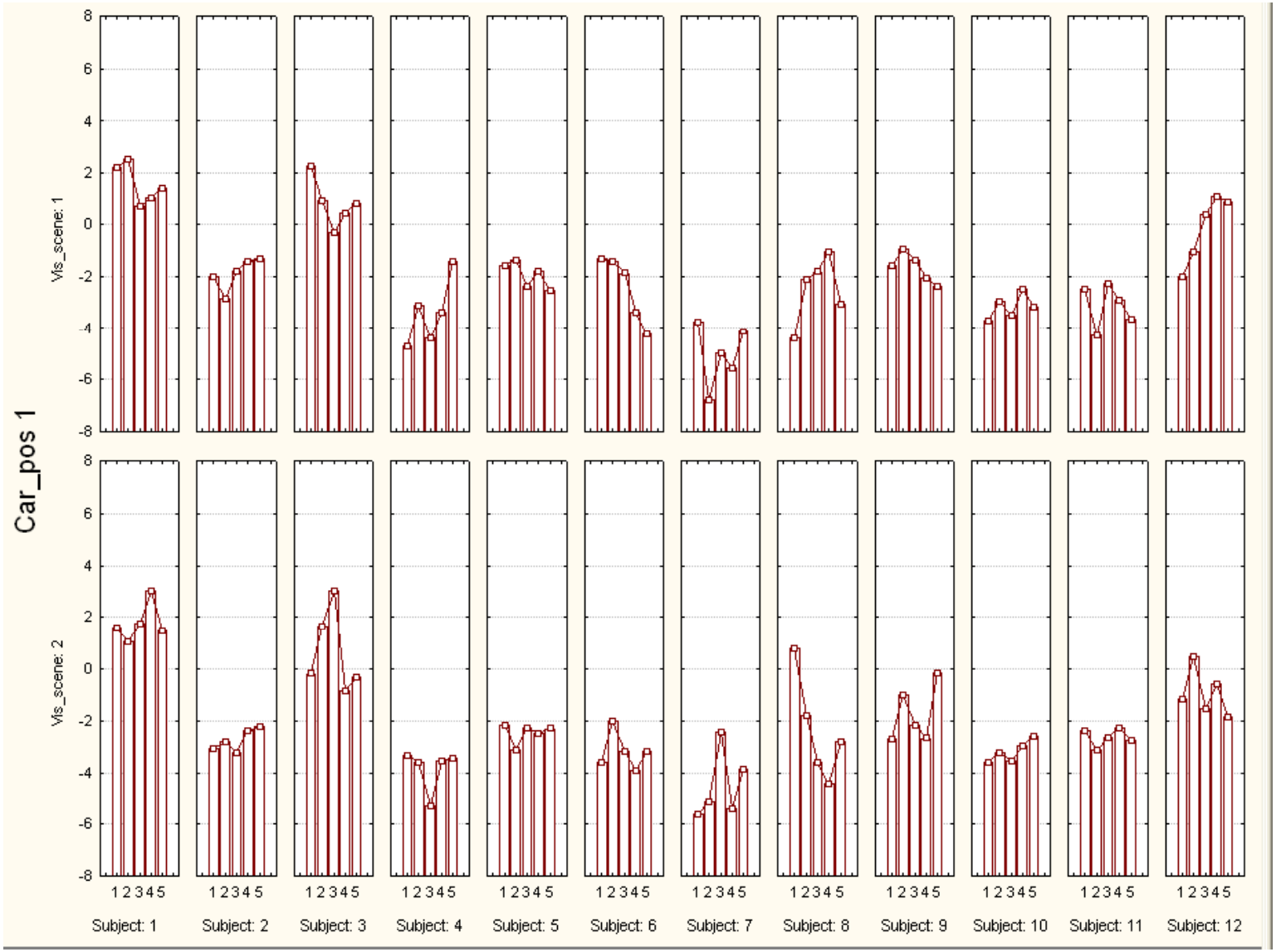
Judged speeds of collision when braking from different speeds are always underestimated (Svenson, Eriksson, et Gonzalez, 2012).

http://www.realite-virtuelle.univmed.fr/

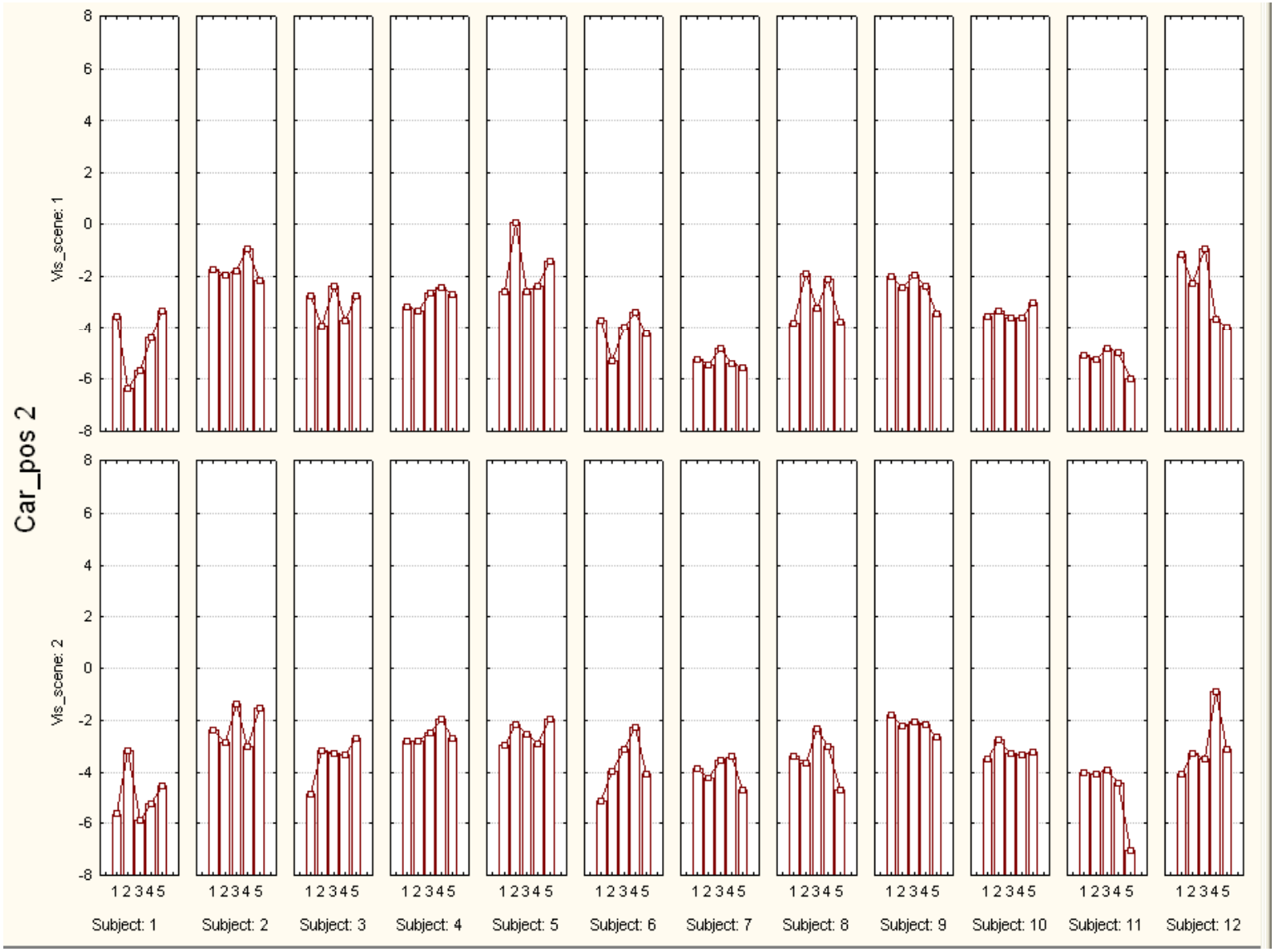
Cmpt


Stopping distance: 40m
Stopping distance: 80m
Final car position to light (m)
0,0
-0,5
-1,0
-1,5
-2,0
-2,5
-3,0
-3,5
-4,0
-4,5
-5,0
-5,5
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor optic flow)
A/V Gain
(Rich optic flow)

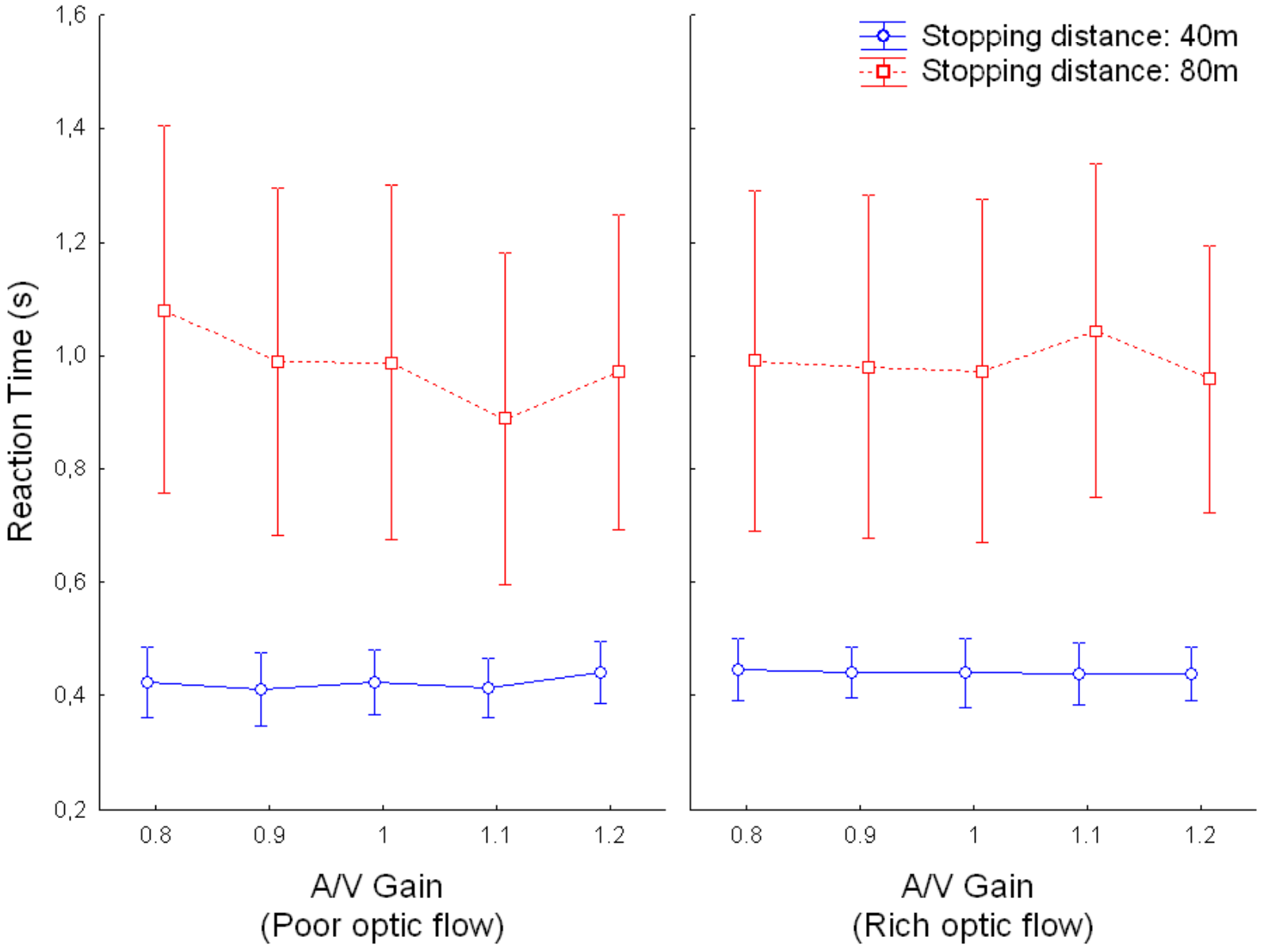
Cmpt


Car_pos 1
Vis_scene: 1
Vis_scene: 2
8
6
4
2
0
-2
-4
-6
-8
1 2 3 4 5
Subject: 1
Subject: 2
Subject: 3
Subject: 4
Subject: 5
Subject: 6
Subject: 7
Subject: 8
Subject: 9
Subject: 10
Subject: 11
Subject: 12

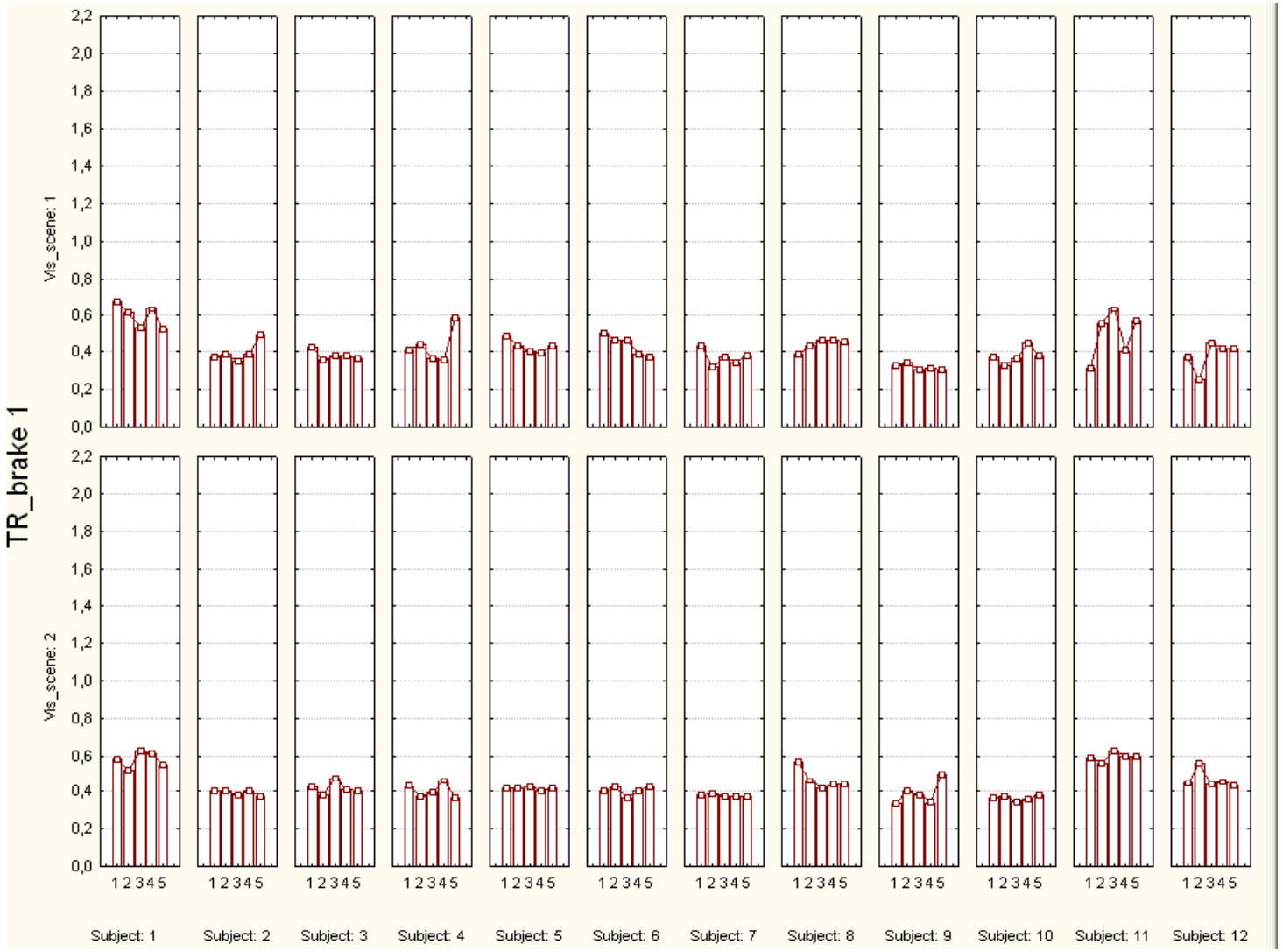
Cmpt


Car_pos 2
Vis_scene: 1
Vis_scene: 2
8
6
4
2
0
-2
-4
-6
-8
1 2 3 4 5
Subject: 1
Subject: 2
Subject: 3
Subject: 4
Subject: 5
Subject: 6
Subject: 7
Subject: 8
Subject: 9
Subject: 10
Subject: 11
Subject: 12

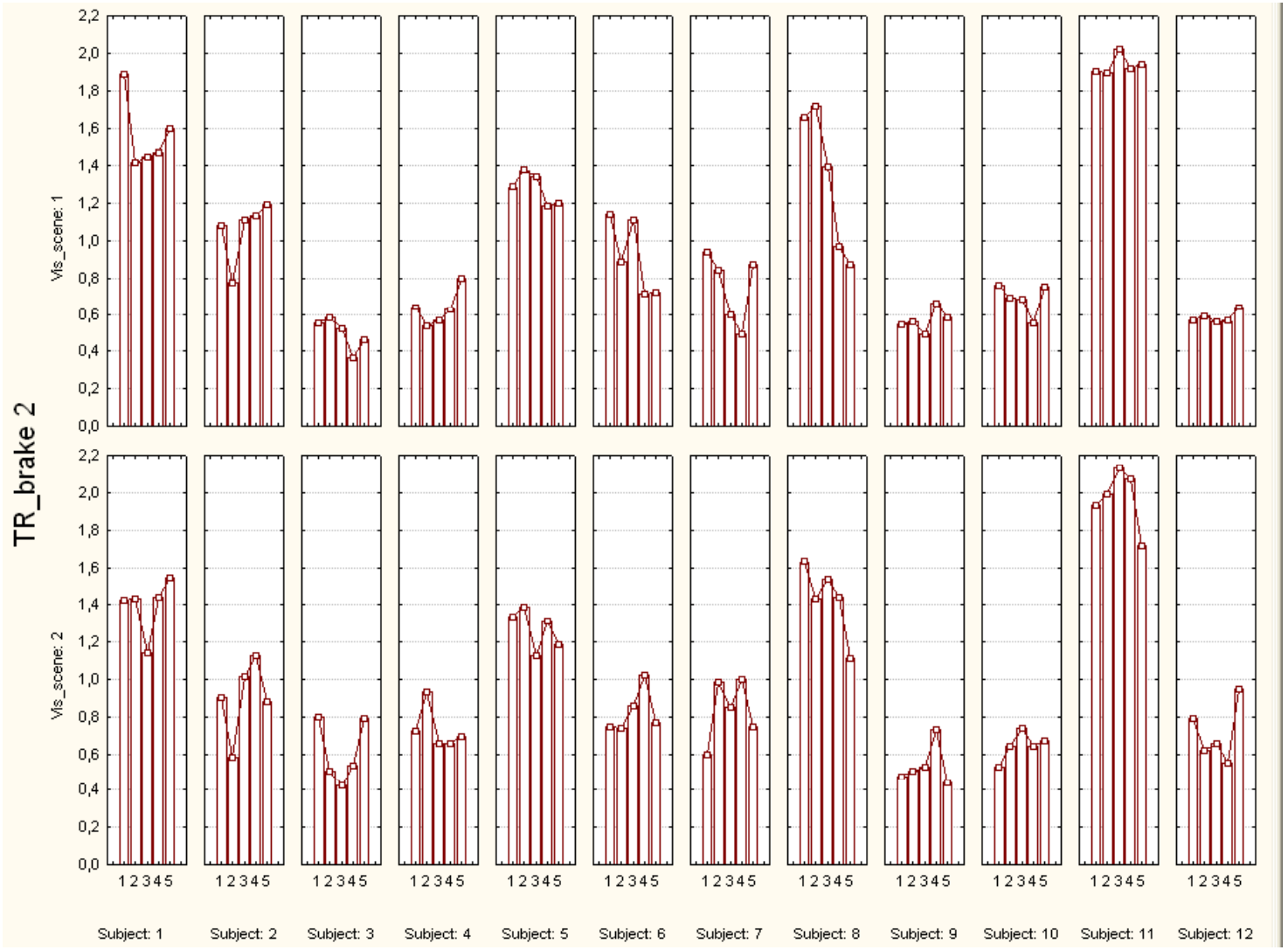
Cmpt


Stopping distance: 40m
Stopping distance: 80m
Reaction Time (s)
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor optic flow)
A/V Gain
(Rich optic flow)

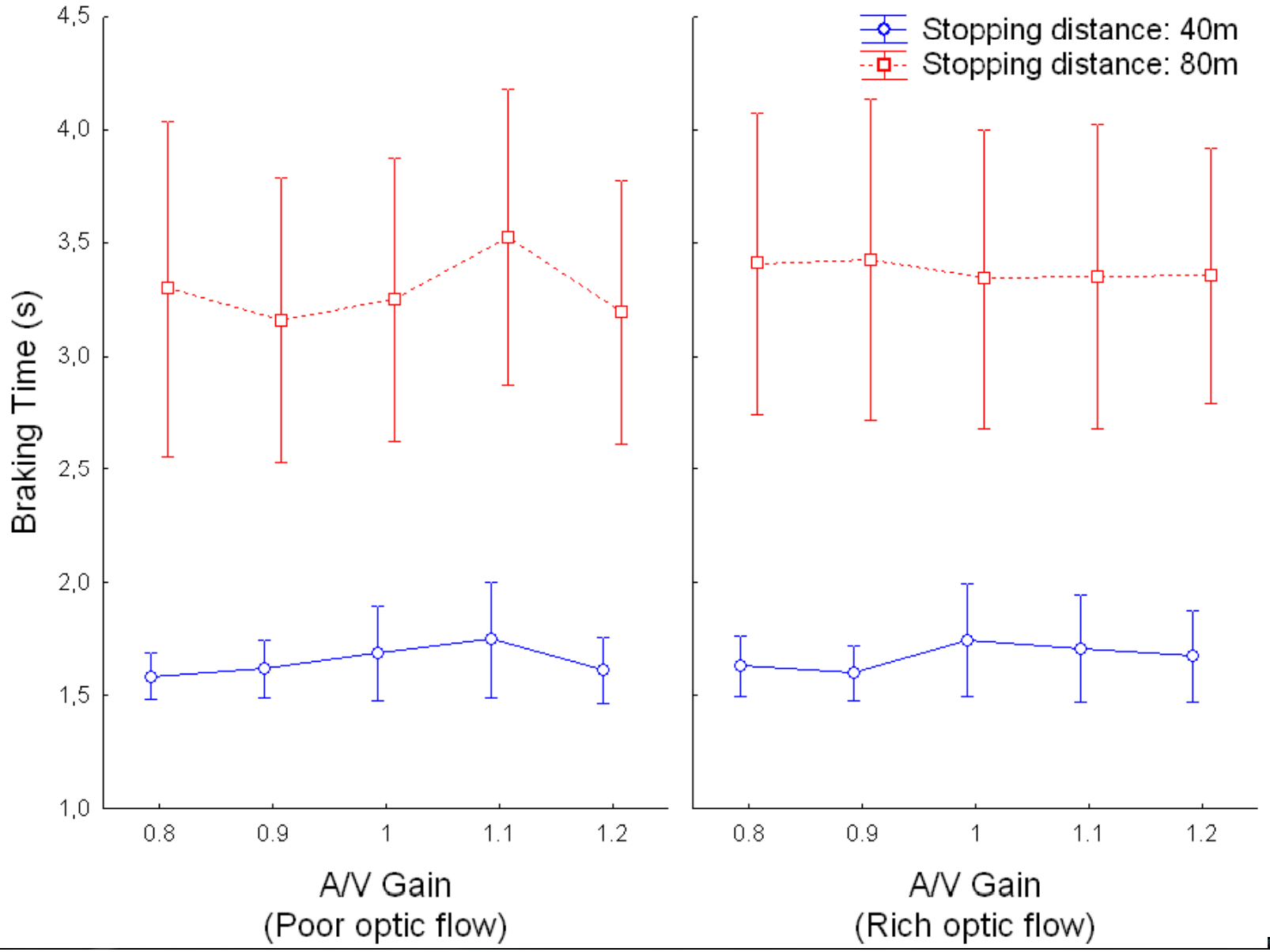
Cmpt


TR_brake 1
Vis_scene: 1
Vis_scene: 2
2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
1 2 3 4 5
Subject: 1
Subject: 2
Subject: 3
Subject: 4
Subject: 5
Subject: 6
Subject: 7
Subject: 8
Subject: 9
Subject: 10
Subject: 11
Subject: 12

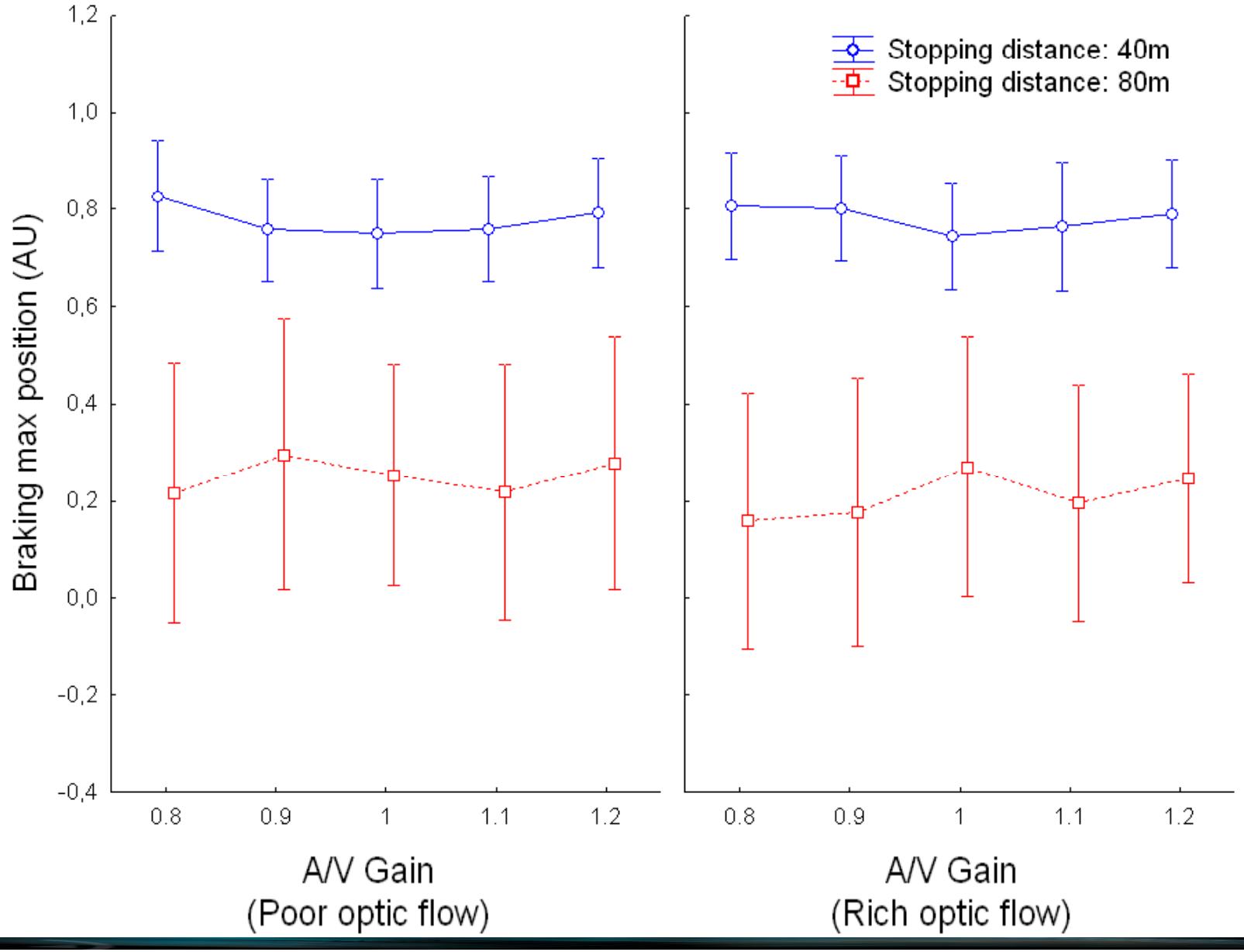
Cmpt


TR_brake 2
Vis_scene: 1
Vis_scene: 2
2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
1 2 3 4 5
Subject: 1
Subject: 2
Subject: 3
Subject: 4
Subject: 5
Subject: 6
Subject: 7
Subject: 8
Subject: 9
Subject: 10
Subject: 11
Subject: 12

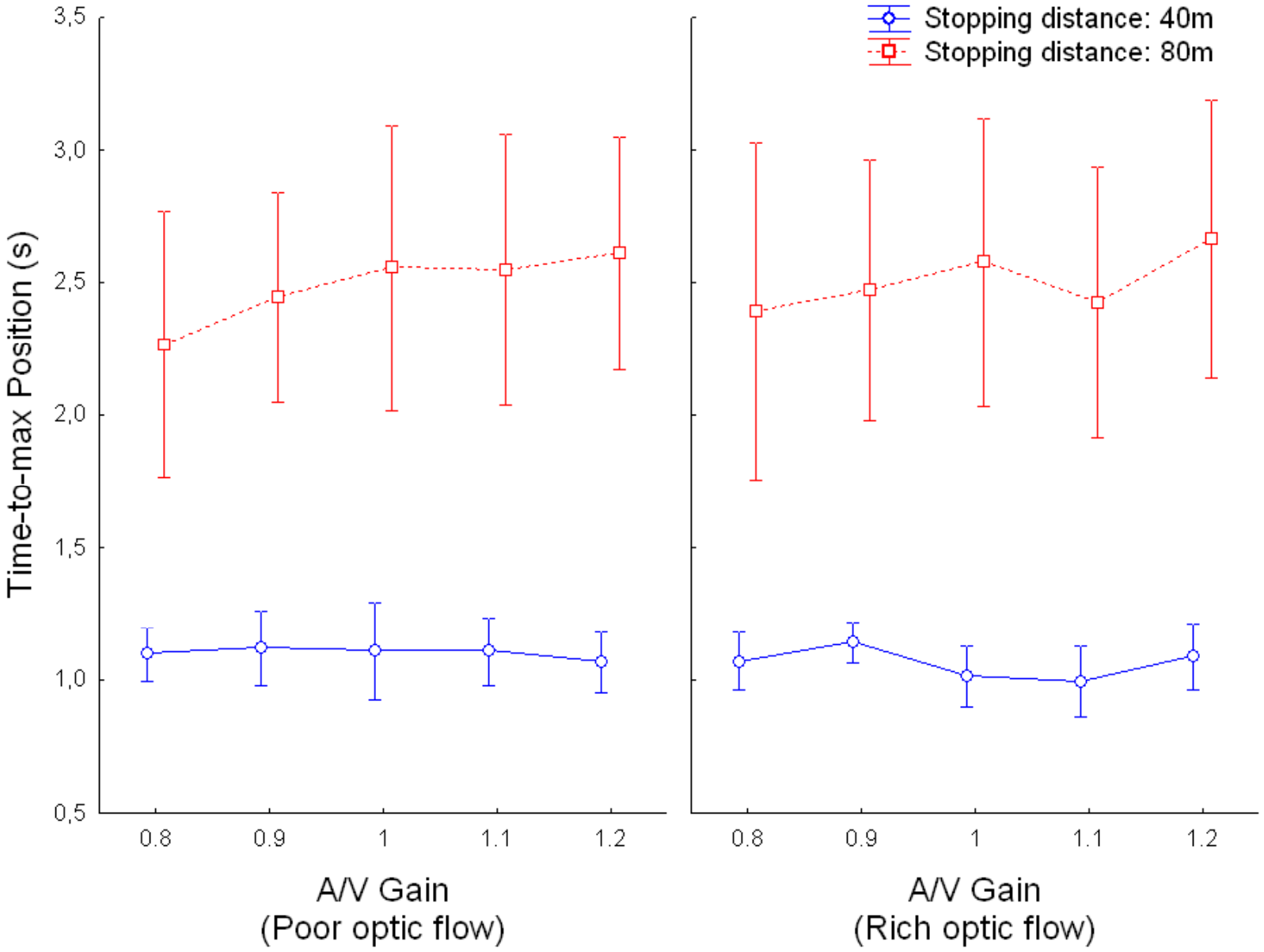
Cmpt


Stopping distance: 40m
Stopping distance: 80m
Braking Time (s)
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor optic flow)
A/V Gain
(Rich optic flow)

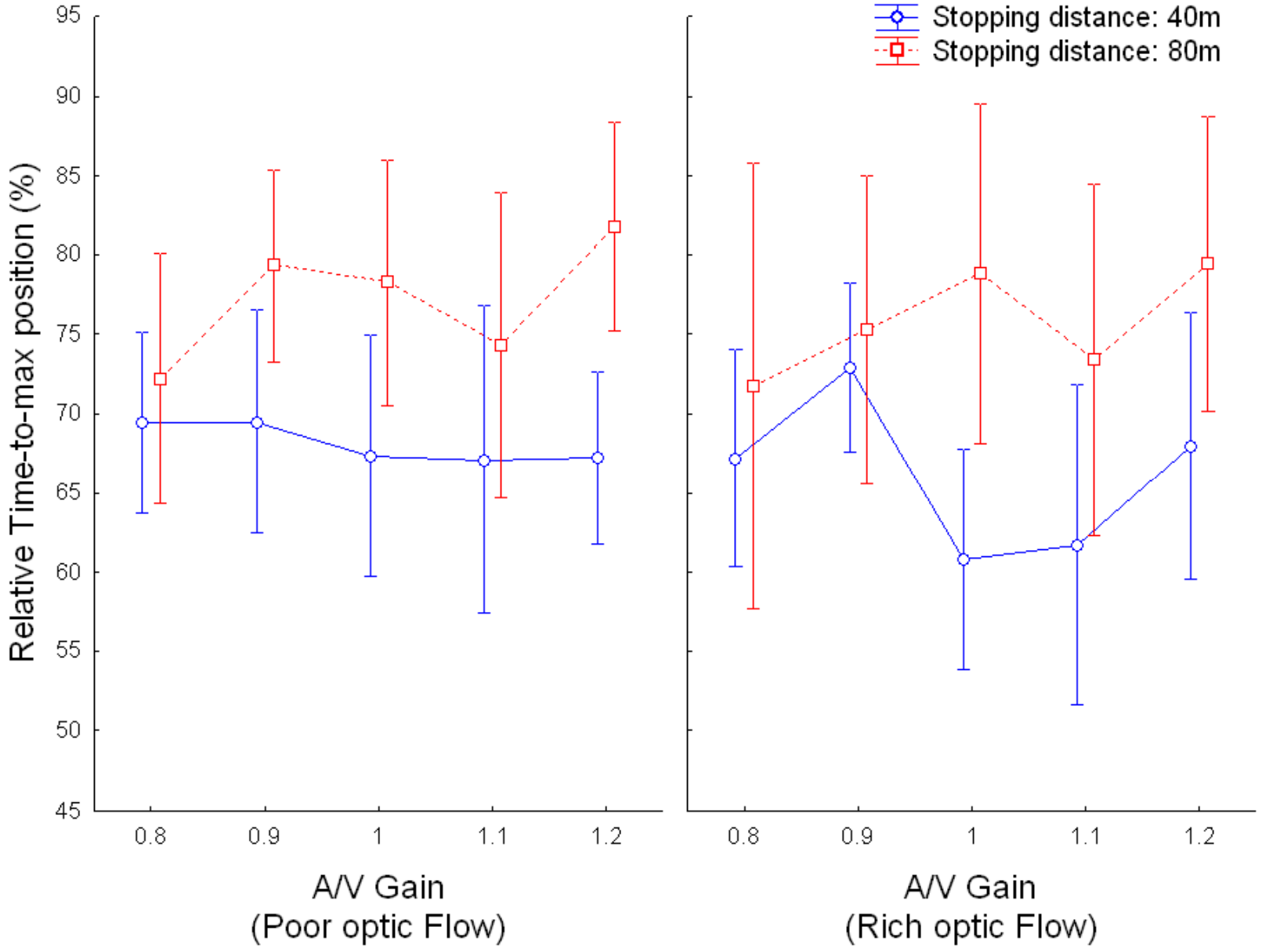
Cmpt


Stopping distance: 40m
Stopping distance: 80m
Braking max position (AU)
1,2
1,0
0,8
0,6
0,4
0,2
0,0
-0,2
-0,4
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor optic flow)
A/V Gain
(Rich optic flow)

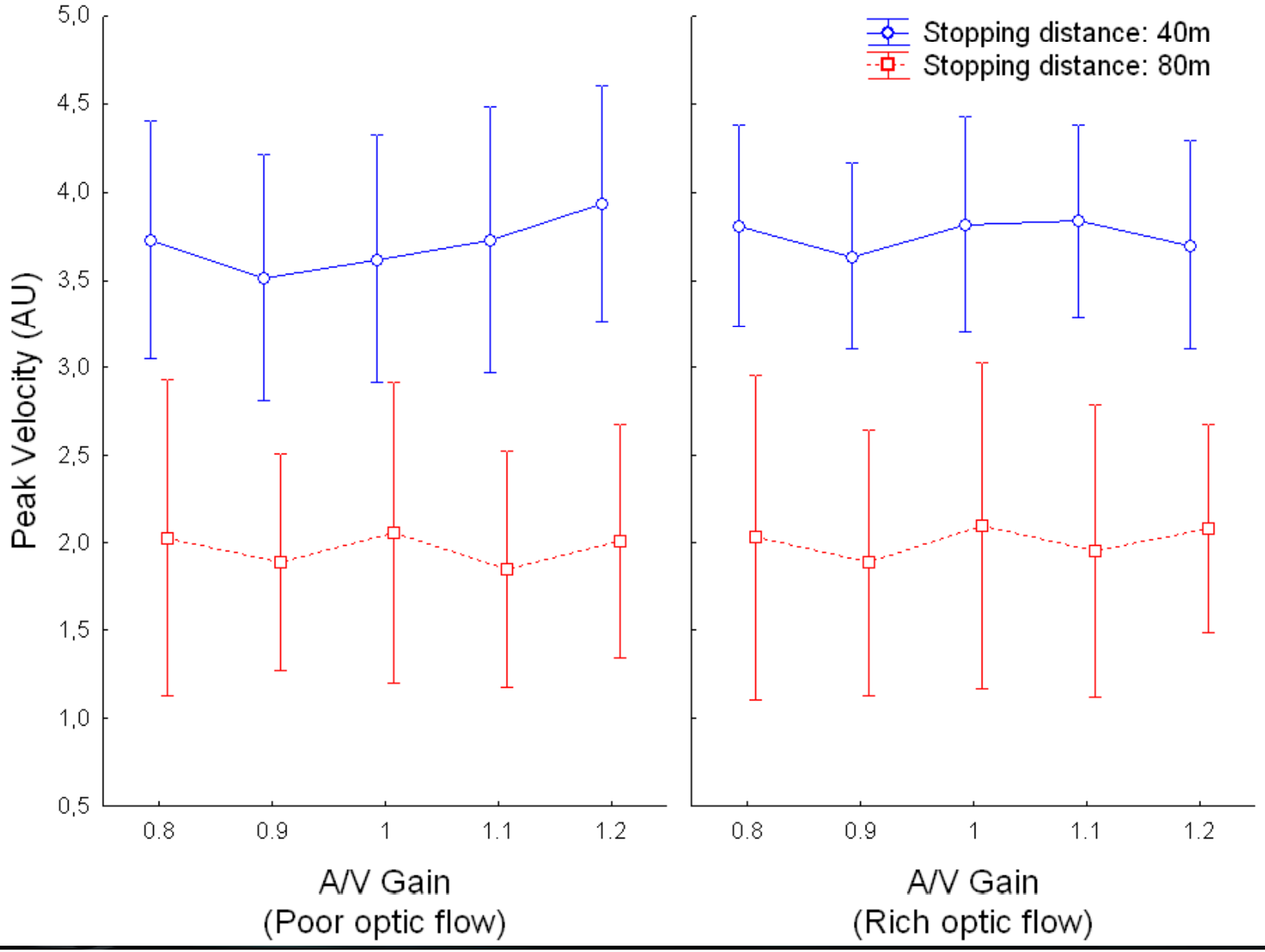
Cmpt


Stopping distance: 40m
Stopping distance: 80m
Time-to-max Position (s)
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor optic flow)
A/V Gain
(Rich optic flow)

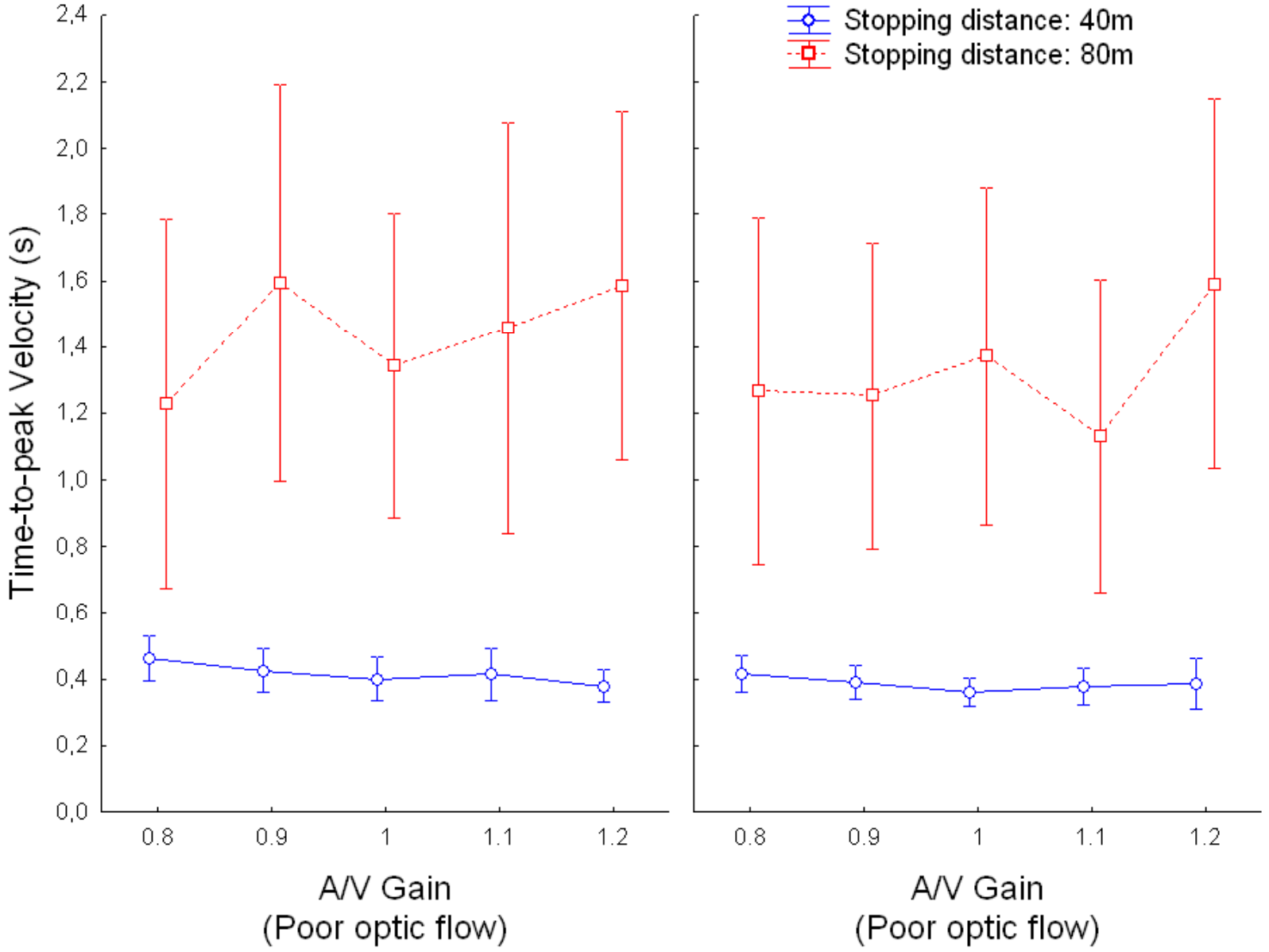
Cmpt


Stopping distance: 40m
Stopping distance: 80m
Relative Time-to-max position (%)
95
90
85
80
75
70
65
60
55
50
45
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor optic Flow)
A/V Gain
(Rich optic Flow)

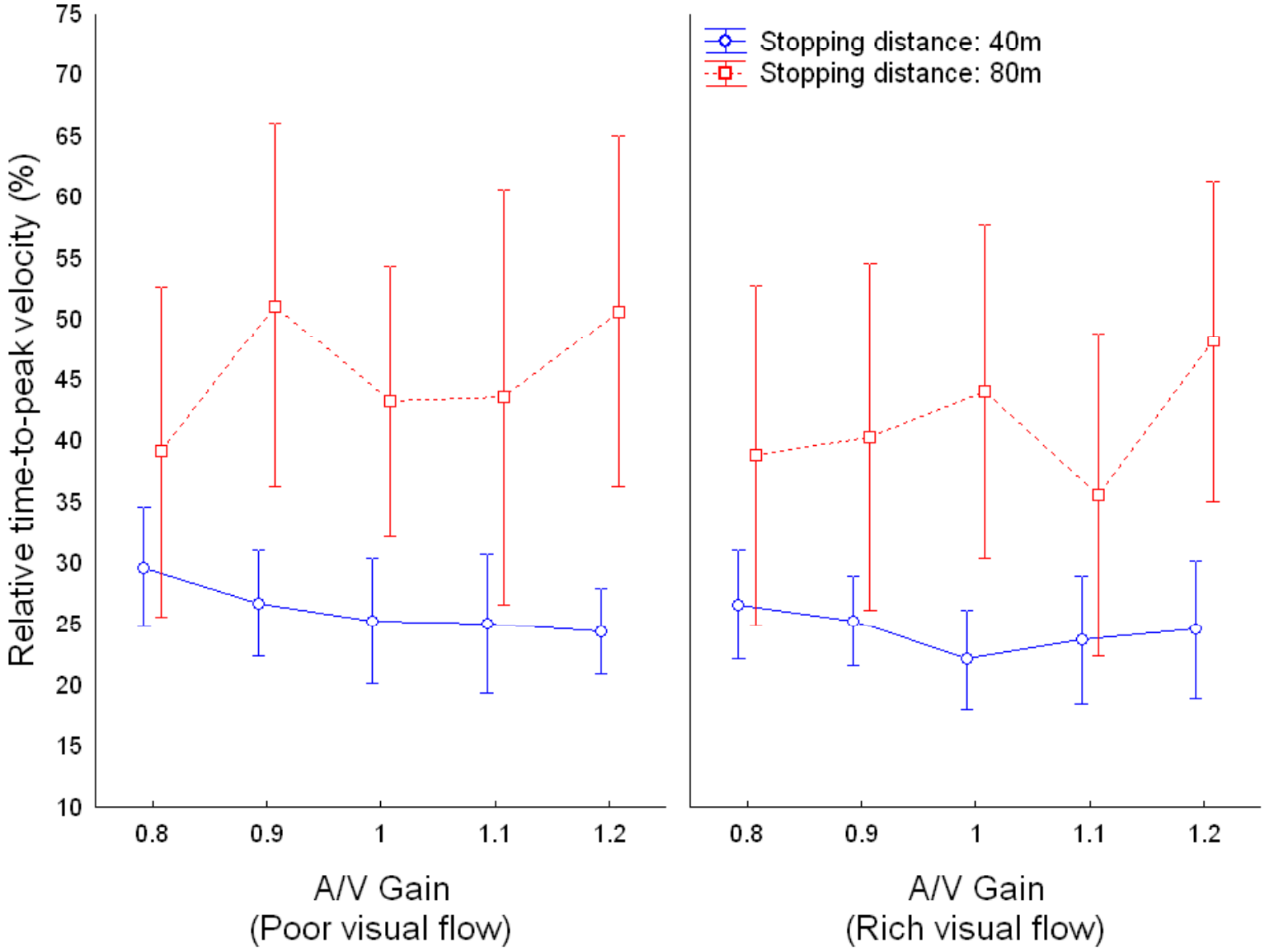
Cmpt


Stopping distance: 40m
Stopping distance: 80m
Peak Velocity (AU)
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor optic flow)
A/V Gain
(Rich optic flow)

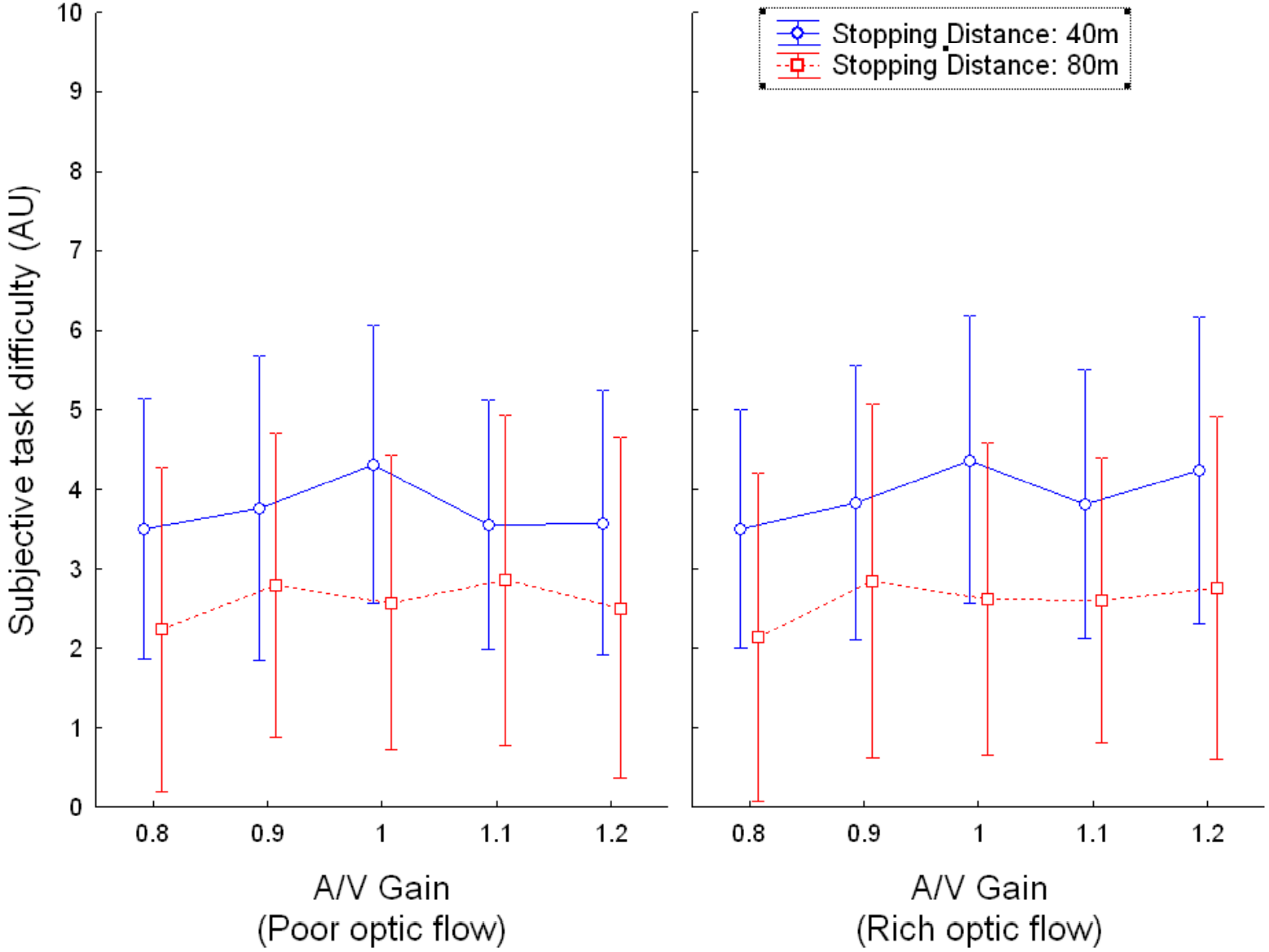
Cmpt


Stopping distance: 40m
Stopping distance: 80m
Time-to-peak Velocity (s)
2,4
2,2
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor optic flow)
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor optic flow)

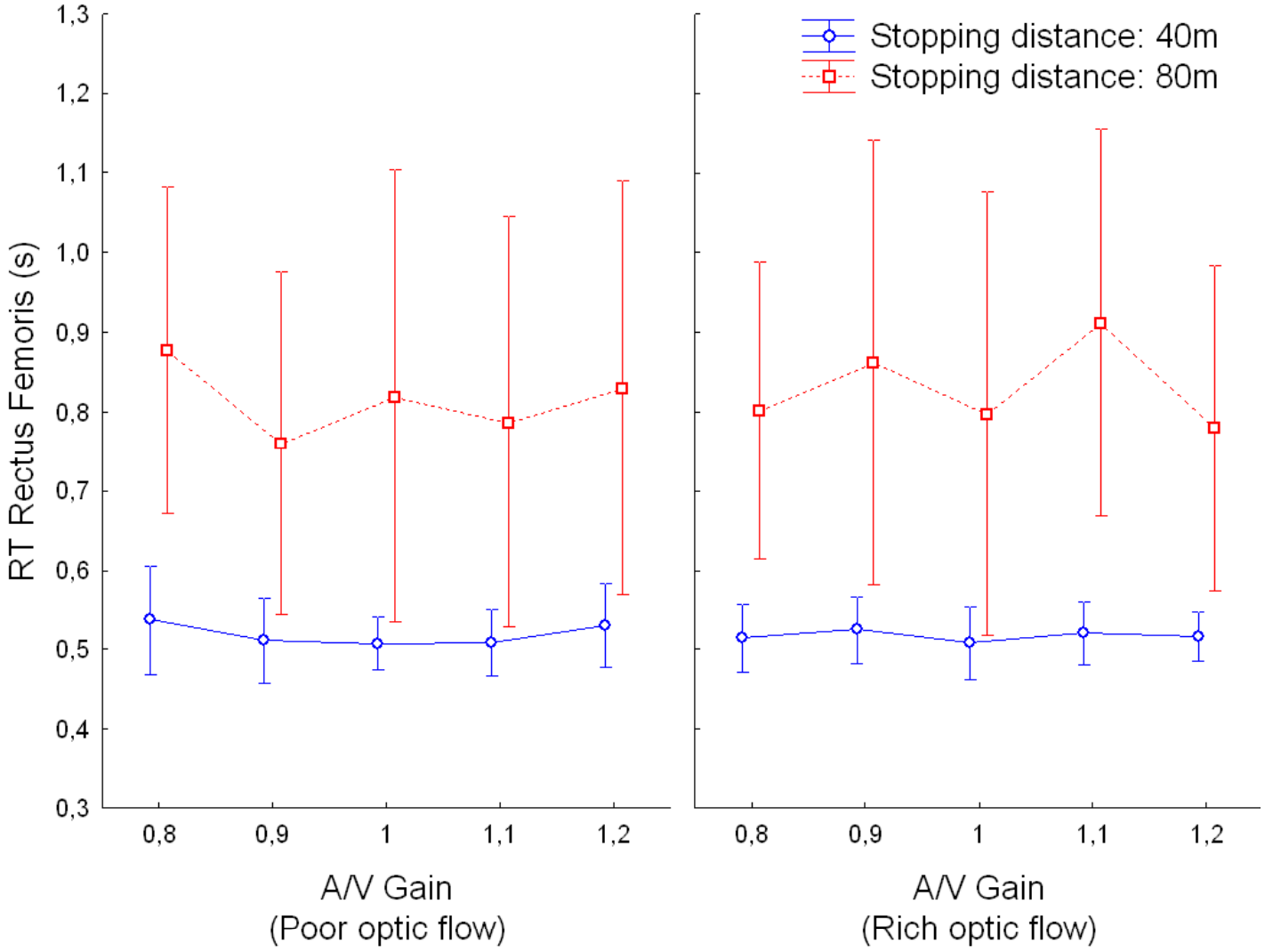
Cmpt


Stopping distance: 40m
Stopping distance: 80m
Relative time-to-peak velocity (%)
75
70
65
60
55
50
45
40
35
30
25
20
15
10
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor visual flow)
A/V Gain
(Rich visual flow)

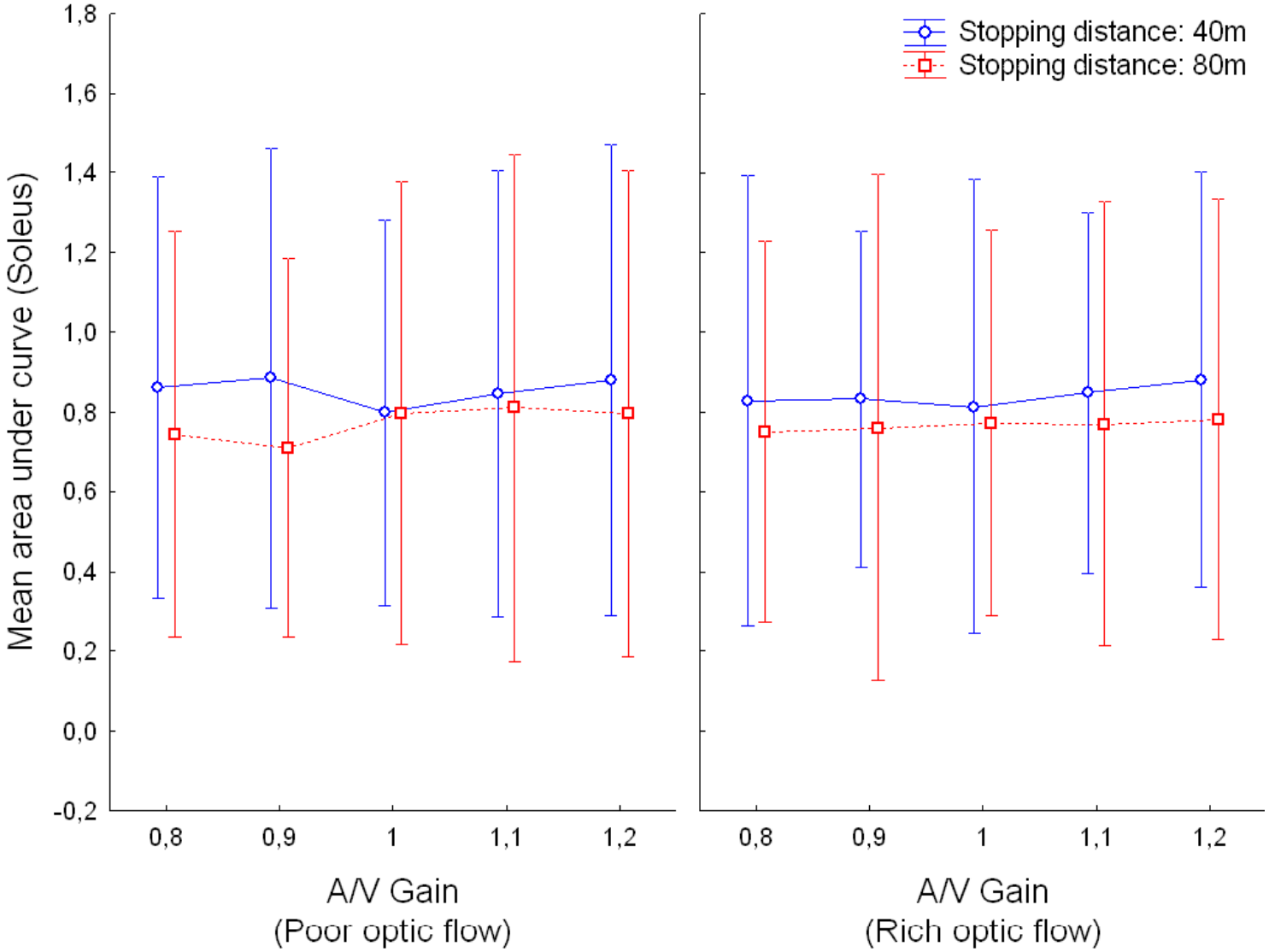
Psych

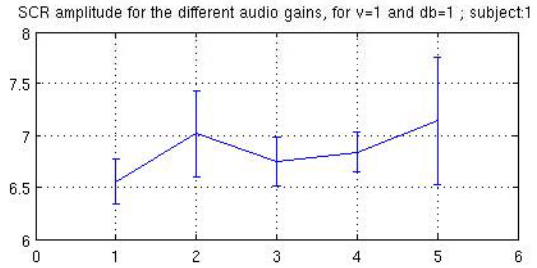

Stopping Distance: 40m
Stopping Distance: 80m
Subjective task difficulty (AU)
0
1
2
3
4
5
6
7
8
9
10
0.8
0.9
1
1.1
1.2
A/V Gain
(Poor optic flow)
A/V Gain
(Rich optic flow)

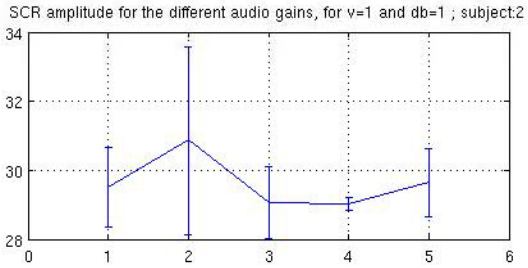
Phy

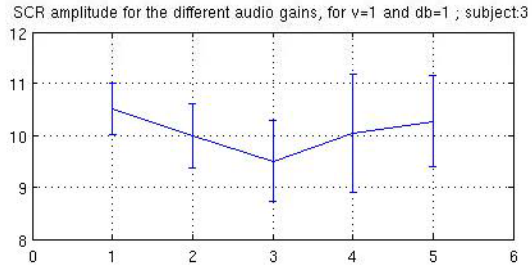

Stopping distance: 40m
Stopping distance: 80m
RT Rectus Femoris (s)
1,3
1,2
1,1
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,8
0,9
1
1,1
1,2
A/V Gain
(Poor optic flow)
A/V Gain
(Rich optic flow)

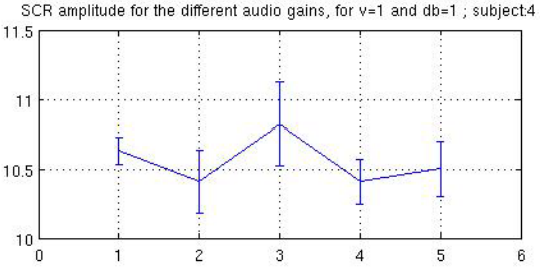
Phy

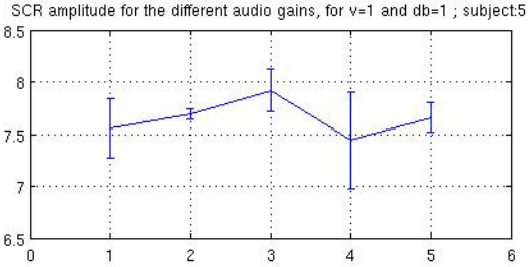

Stopping distance: 40m
Stopping distance: 80m
Mean area under curve (Soleus)
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
-0,2
0,8
0,9
1
1,1
1,2
A/V Gain
(Poor optic flow)
A/V Gain
(Rich optic flow)

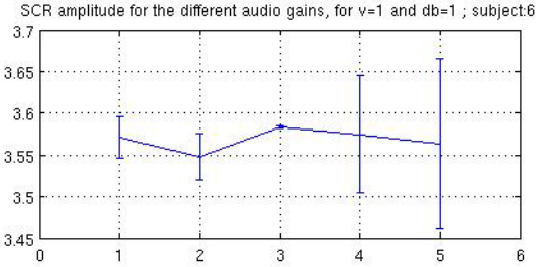


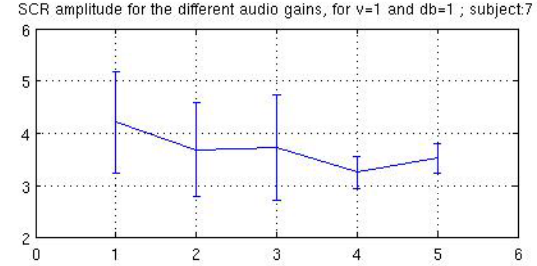








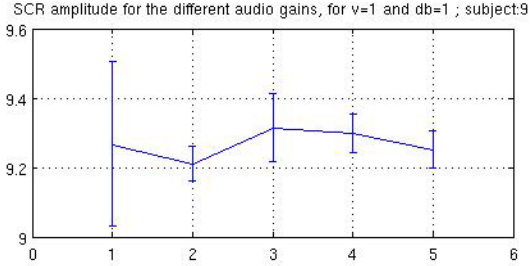


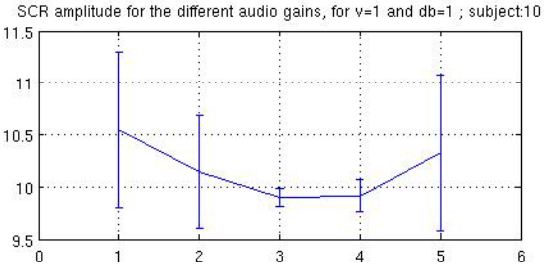


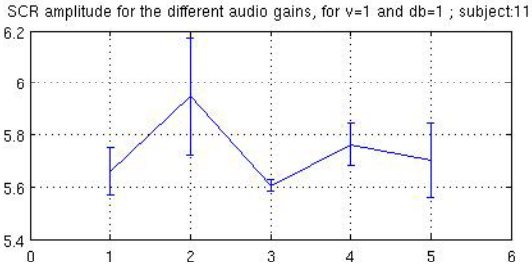
SC peak

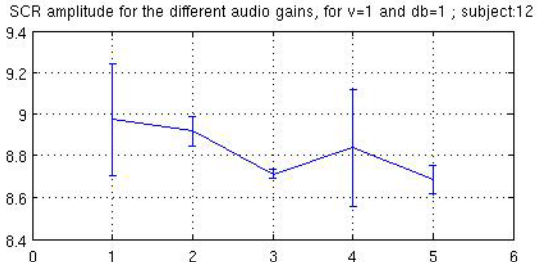
Phy

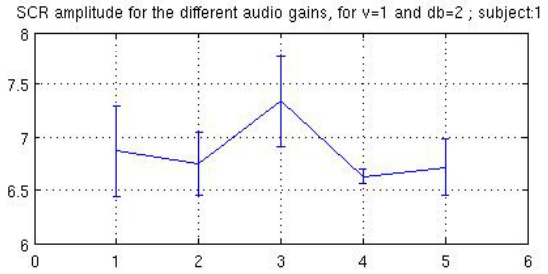
scene pauvre ; distance d'arrêt 40m

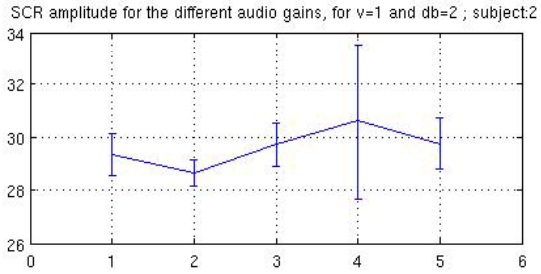


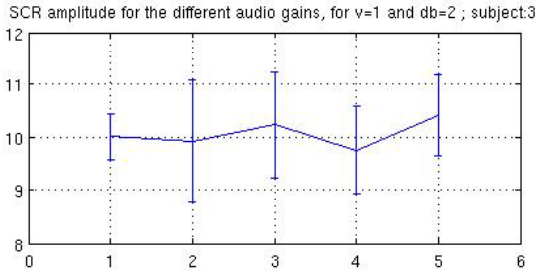


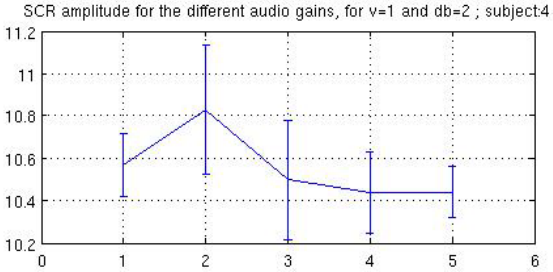


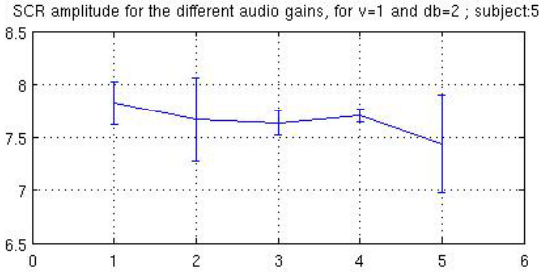


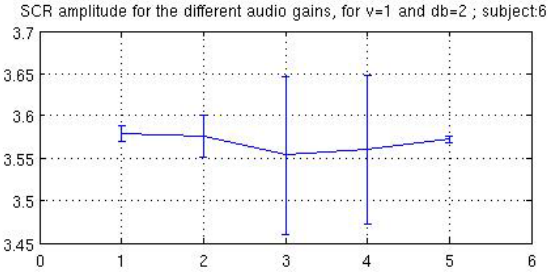


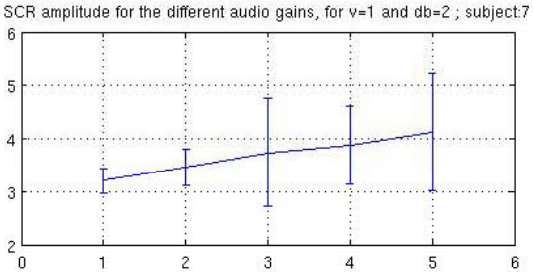








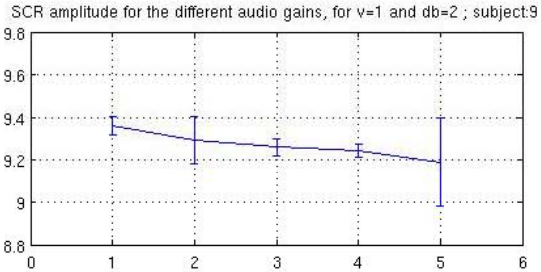


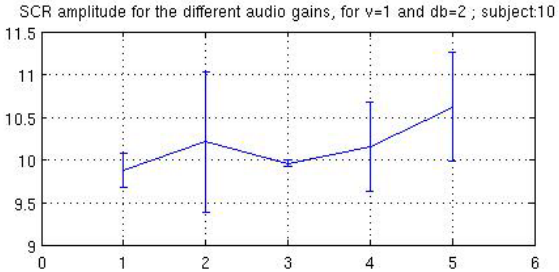


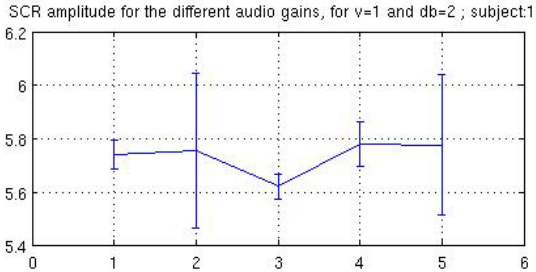
Phy

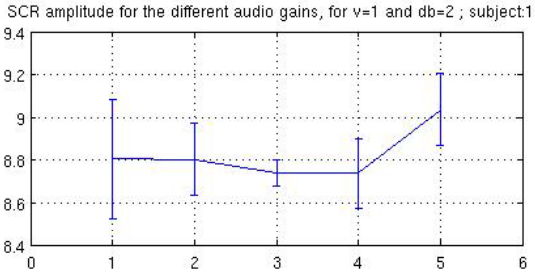
SC peak

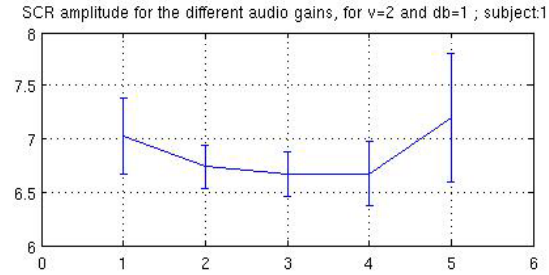
scene pauvre ; distance d'arrêt 80m

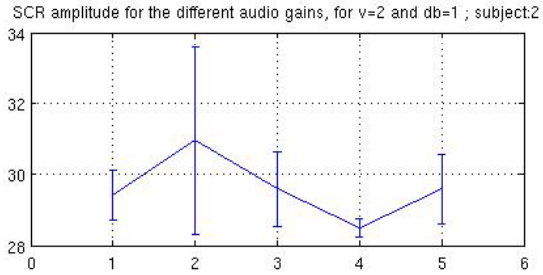


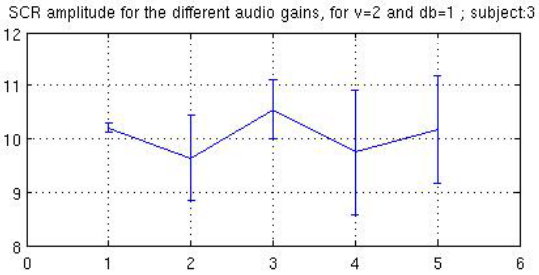


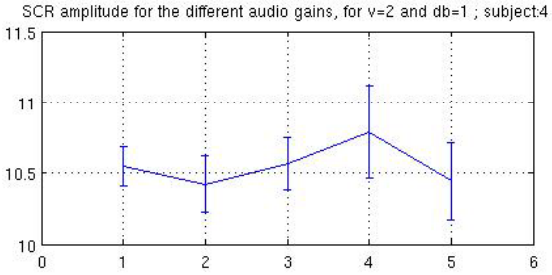


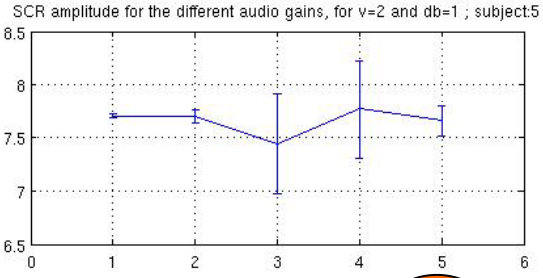


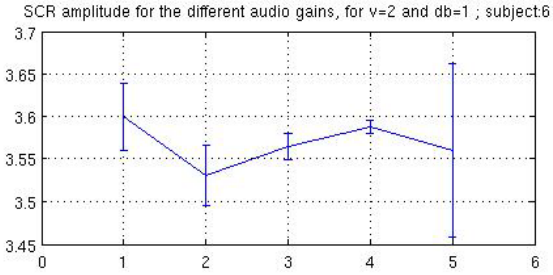


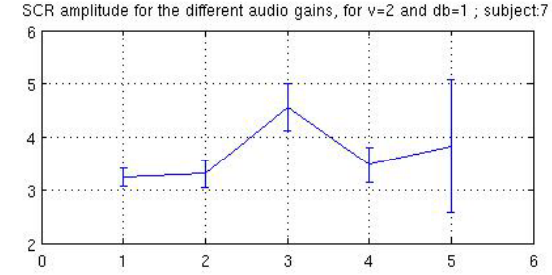








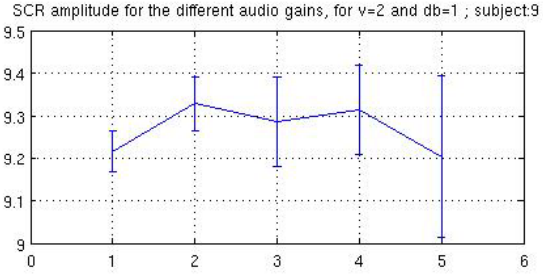


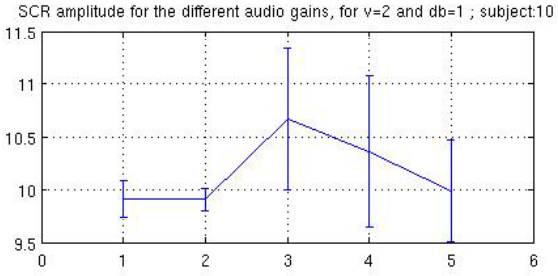


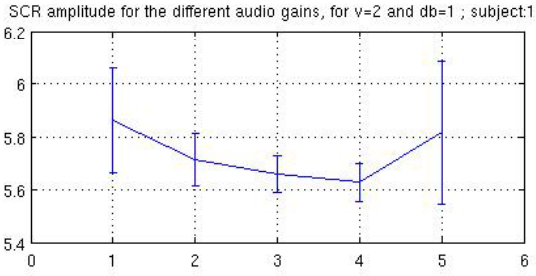
Phy

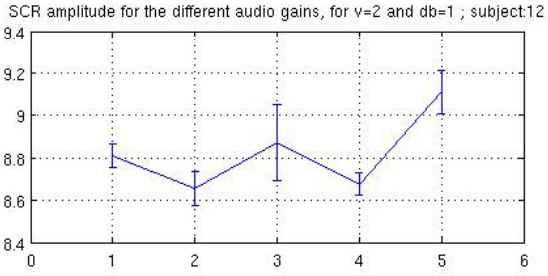
SC peak

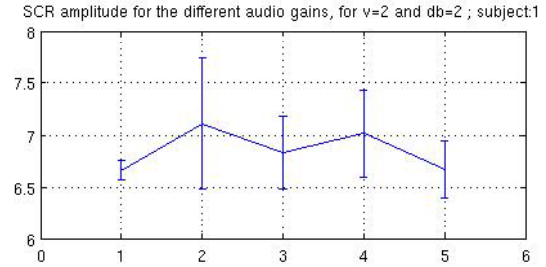
scene riche ; distance d'arrêt 40m

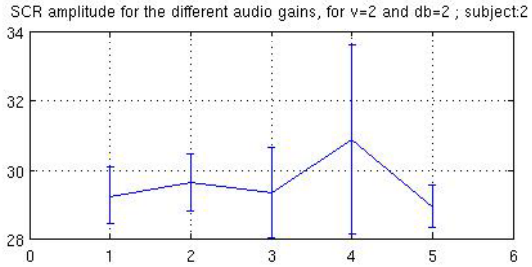


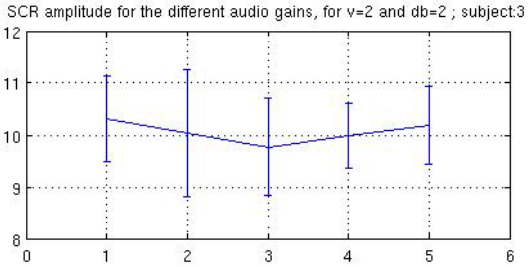


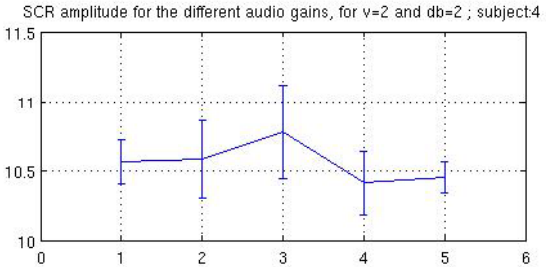


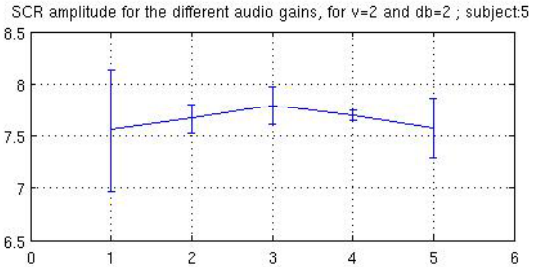


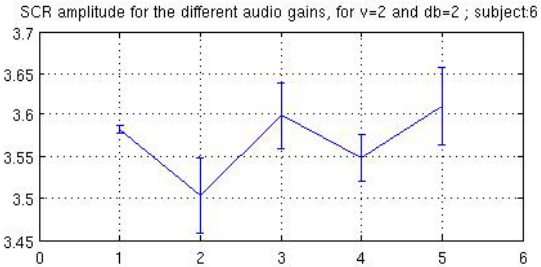


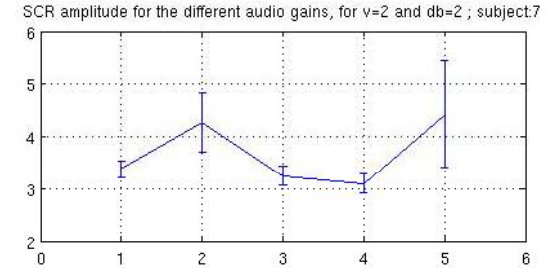








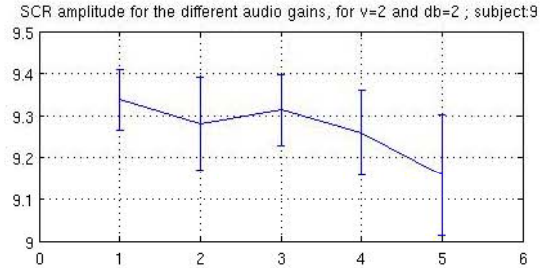


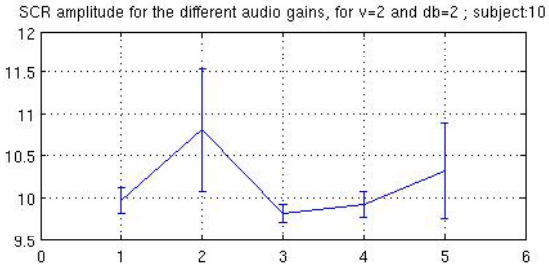


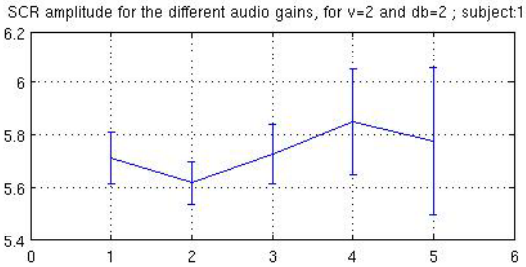
Phy

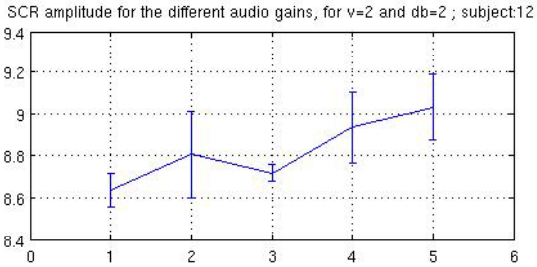
SC peak

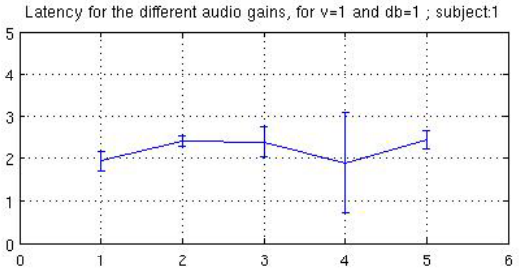
scene riche ; distance d'arrêt 80m

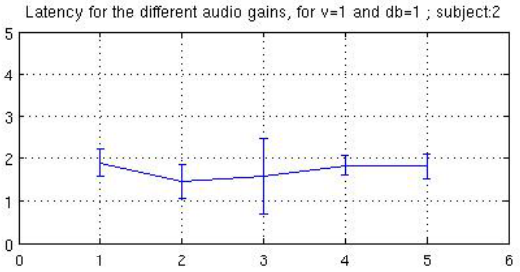


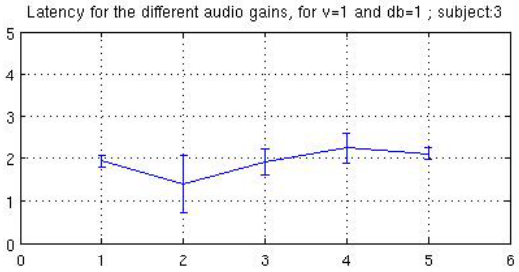


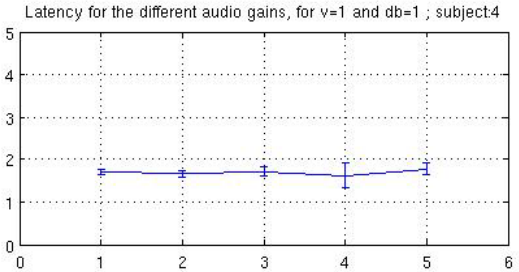


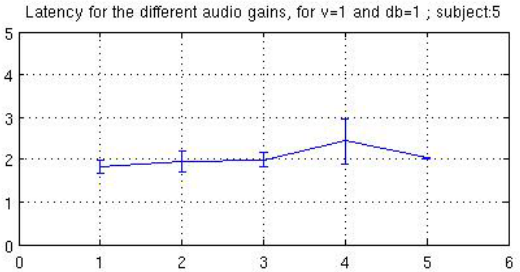


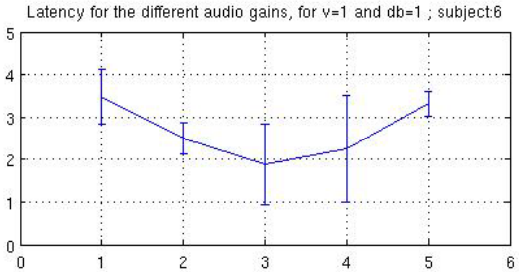


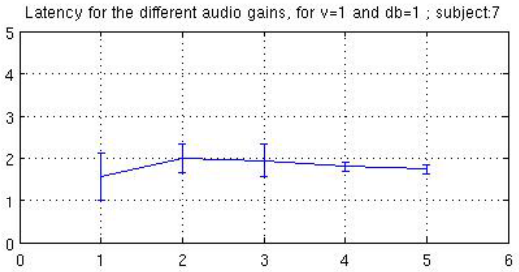








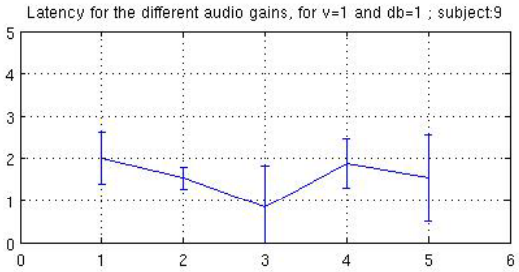


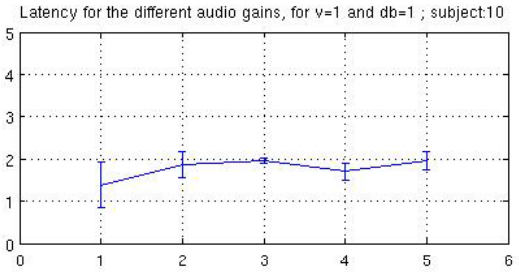


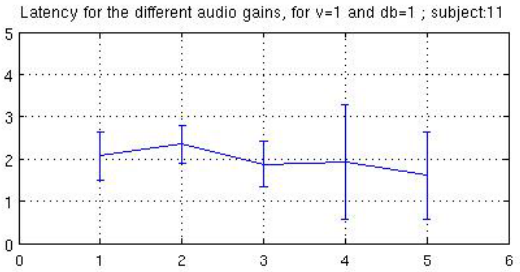
Phy

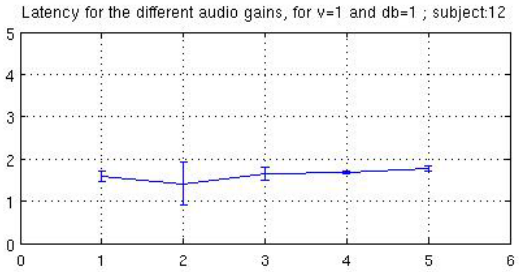
SC latency

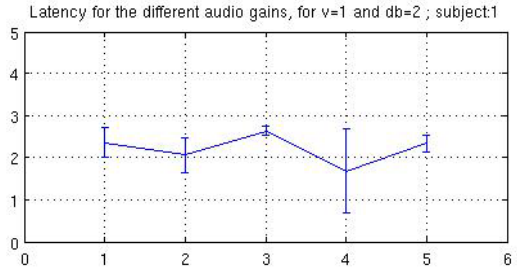
scene pauvre ; distance d'arrêt 40m

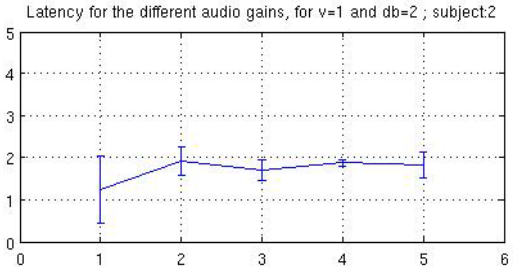


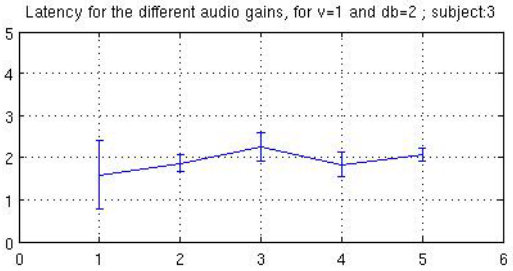


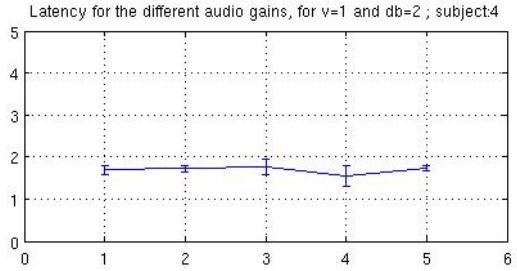


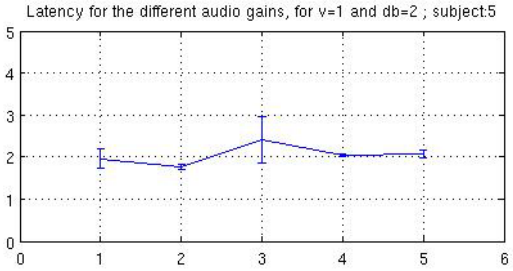


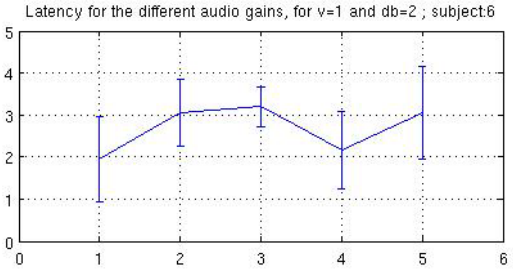


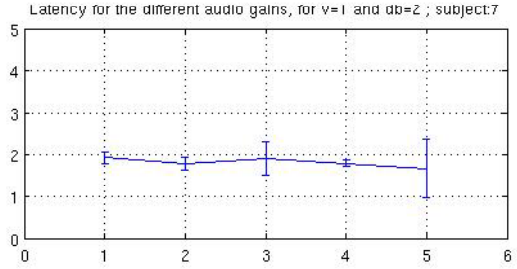








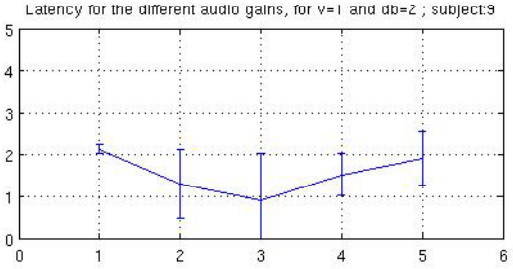


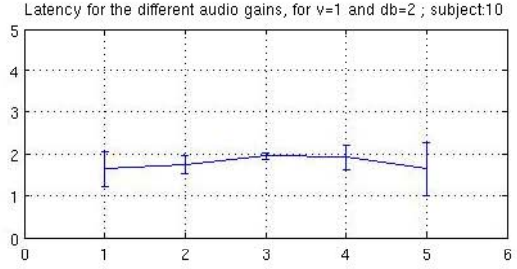


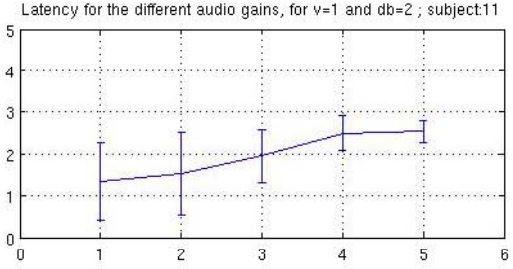
Phy

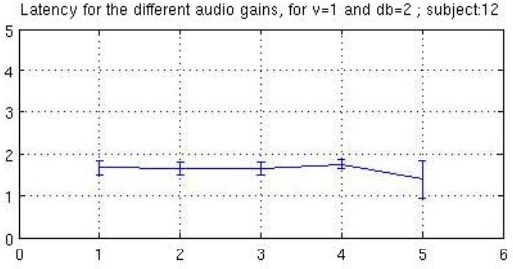
SC latency

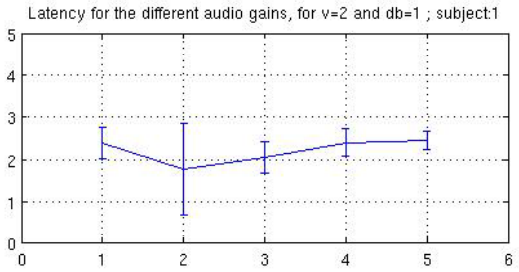
scene pauvre ; distance d'arrêt 80m

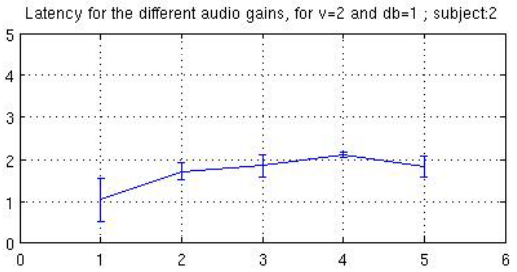


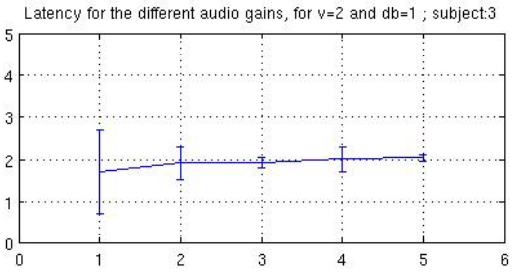


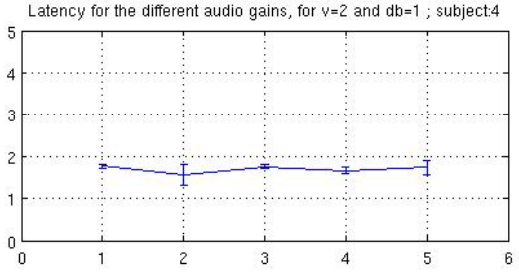


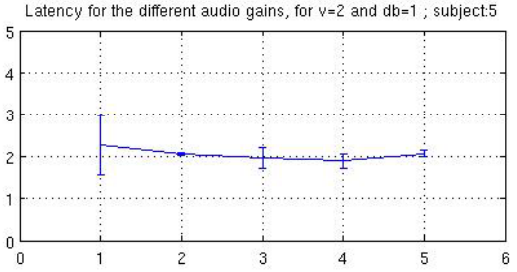


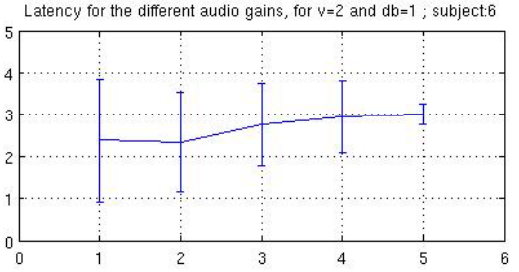


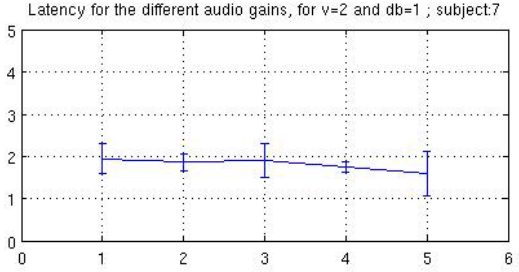








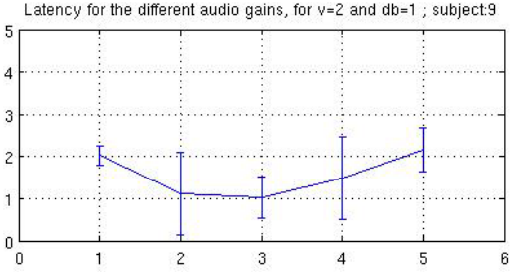


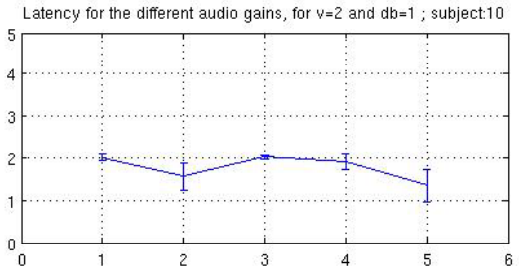


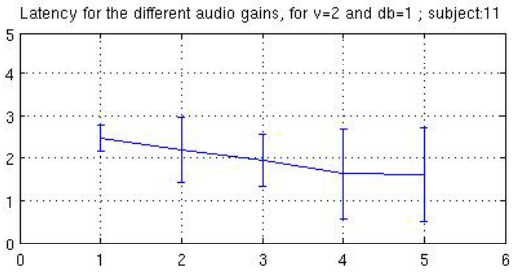
Phy

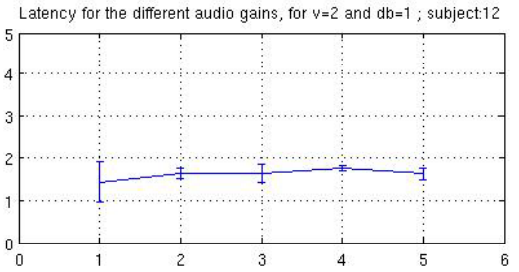
SC latency

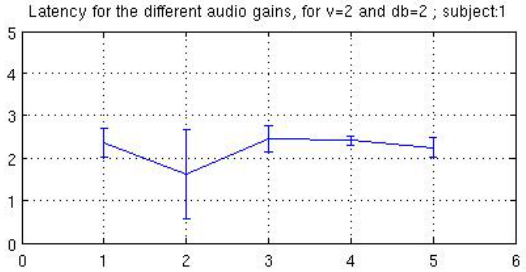
scene riche ; distance d'arrêt 40m

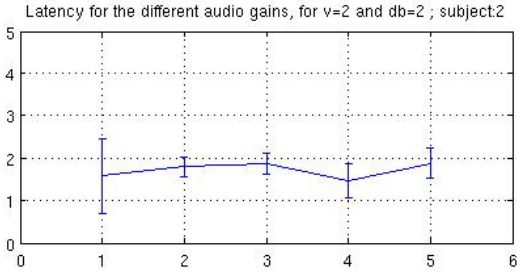


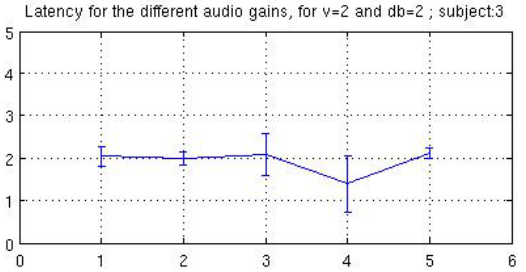


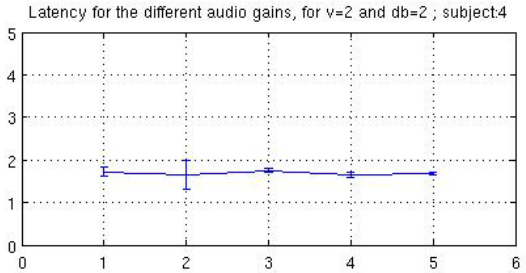


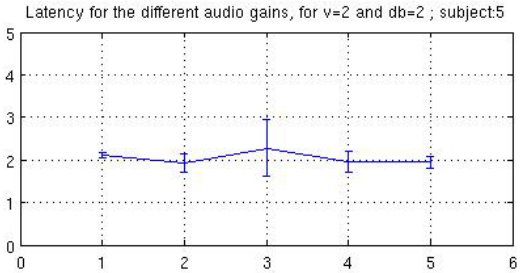


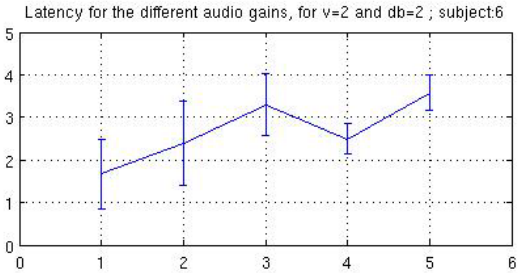


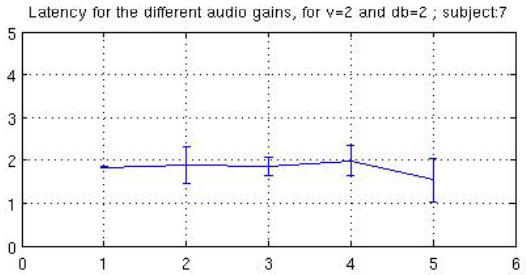












Phy

SC latency

scene riche ; distance d'arrêt 80m