Exploring complex cognitive functions and brain networks using eye-tracking

Introduction to cognitive science

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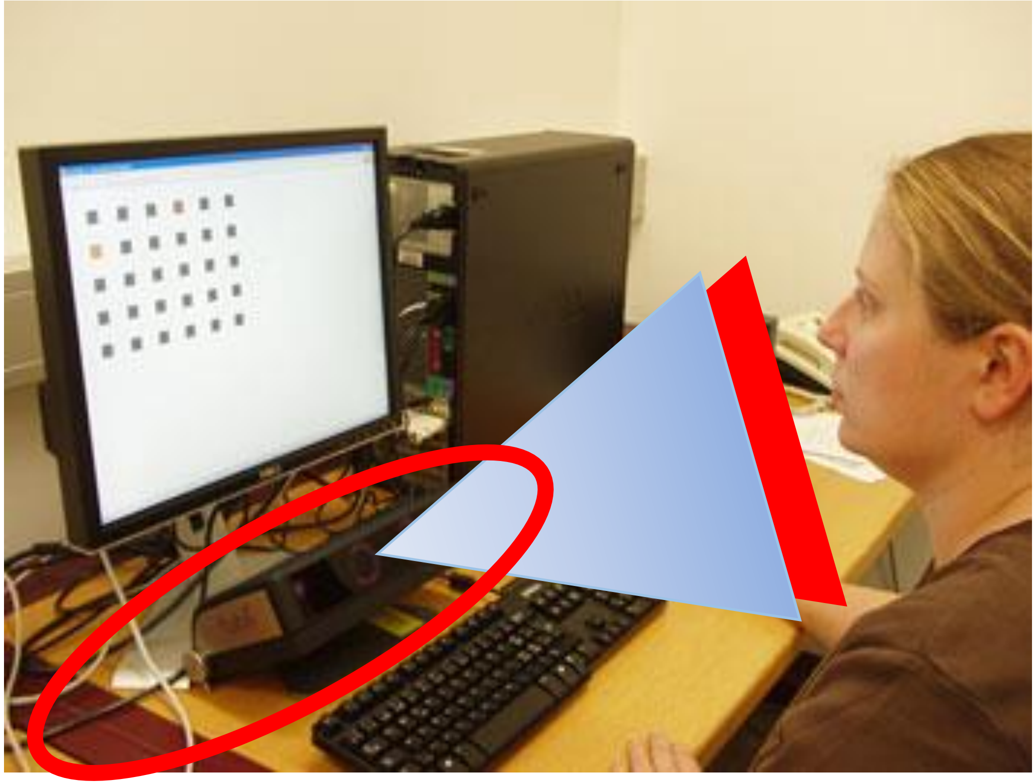
Outline

- Eye-tracking: how does it work?
- How to use eye-tracking when investigating complex cognitive funtctions: example of attentional set shifting
- Exploring basic brain networks using eye-tracking

Eye-tracking: how does it work?

Video-based eye-tracking

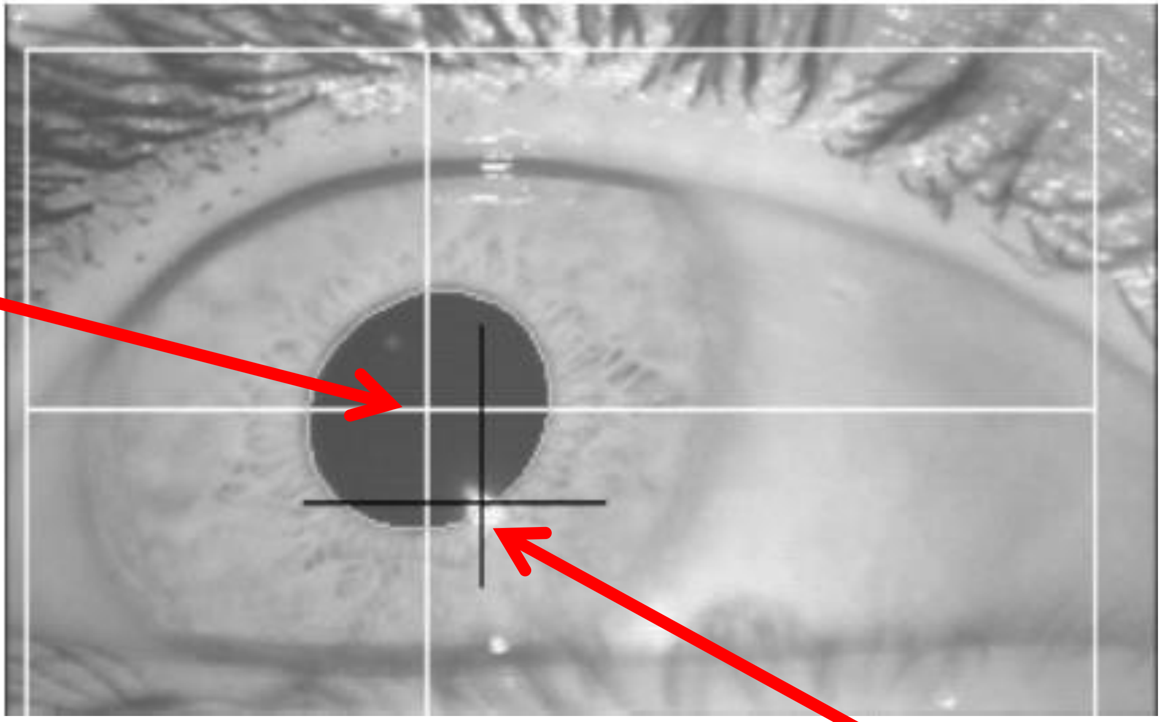
Infrared light source



Video-camera

Video-based eye-tracking

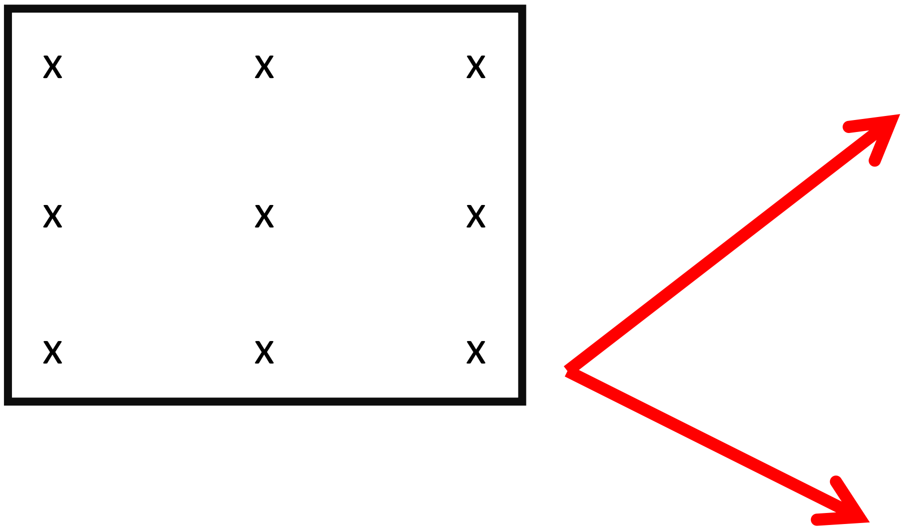
The centre of the pupil

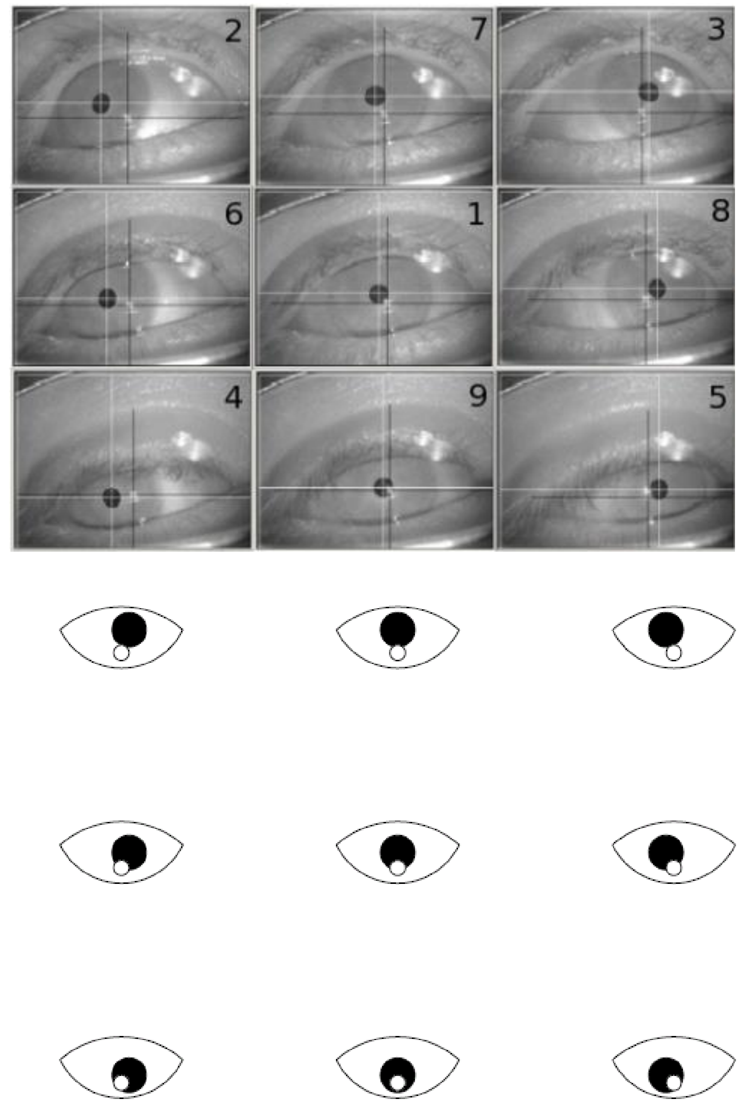


Reflecion of infrared light from the cornea (corneal reflection)

Video-based eye-tracking

Calibration

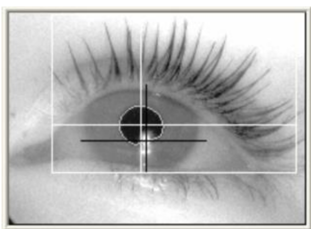


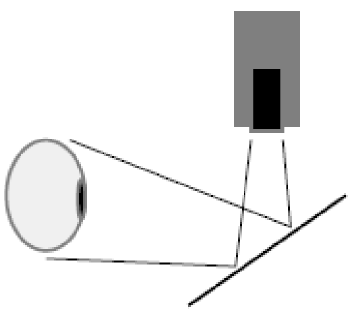


After succesful calibration the gaze direction can be computed from the relative position of the two points (pupil and CR)

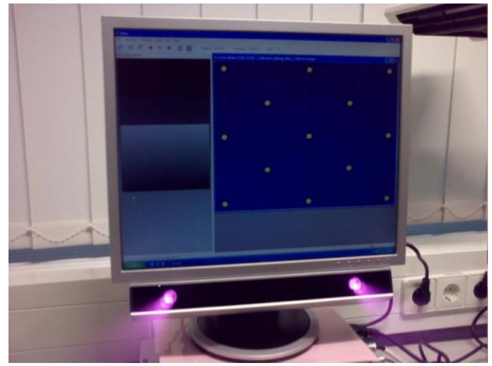
Different video-based eye-trackers

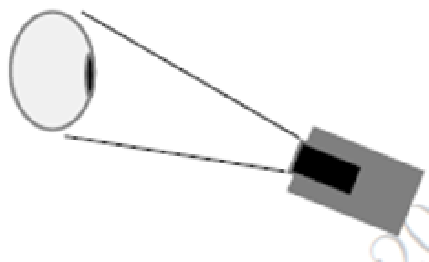
Tower-mounted



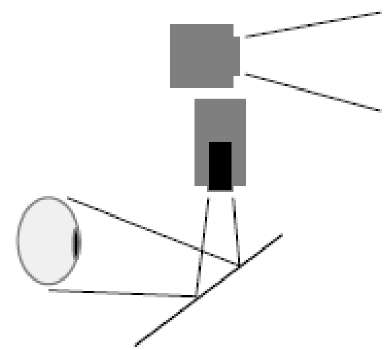


Remote





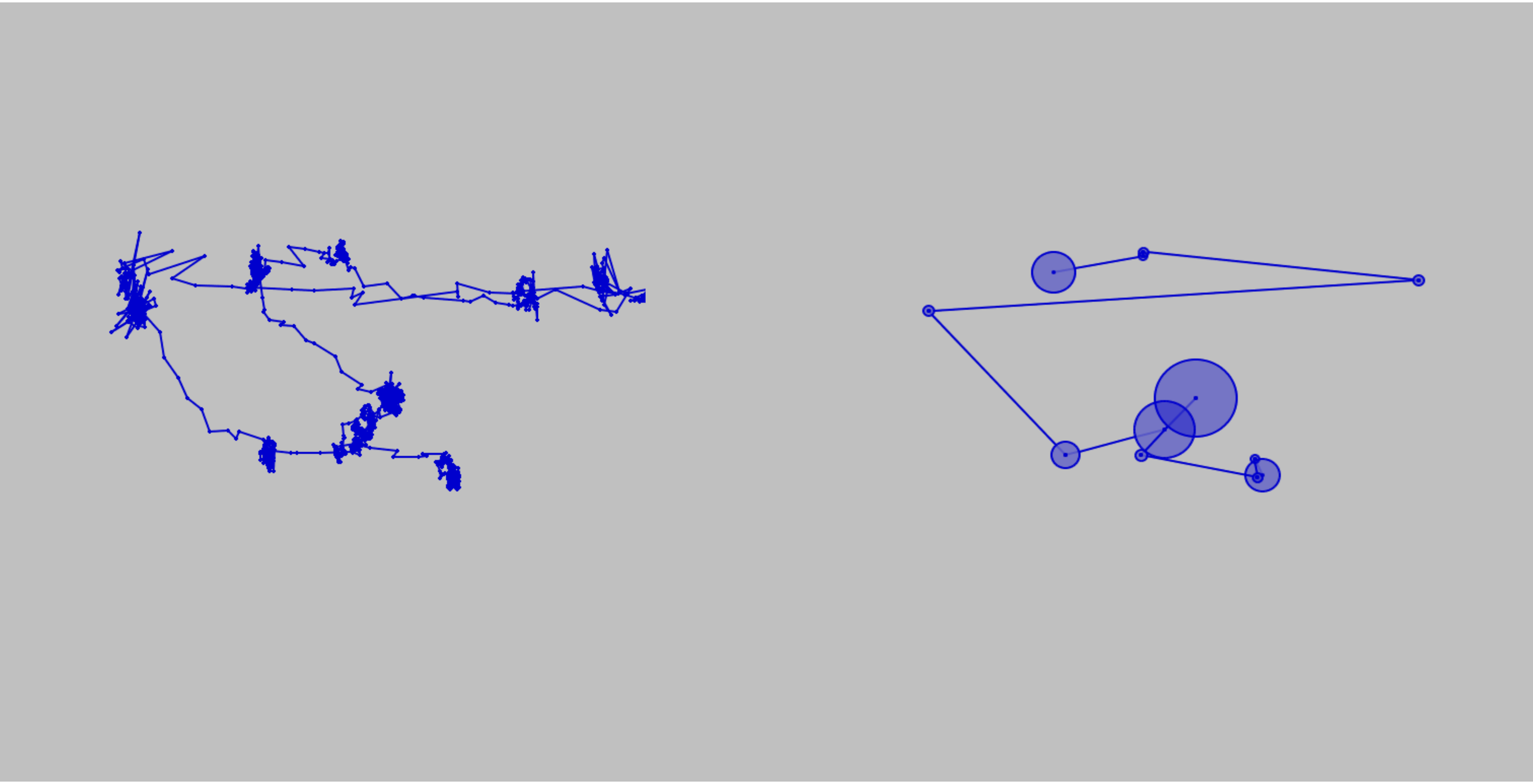
Head-mounted



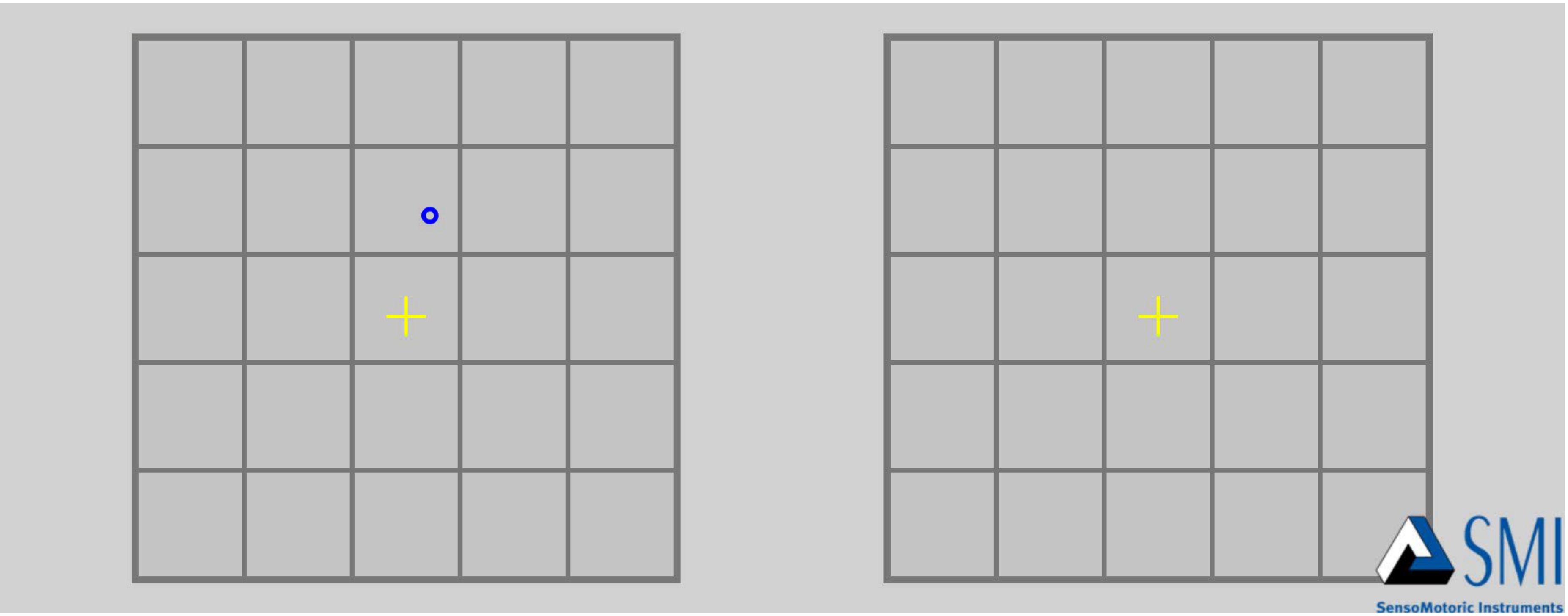
Validity

Data quality

Data processing



Data processing



Encoding → Delay → Retrieval

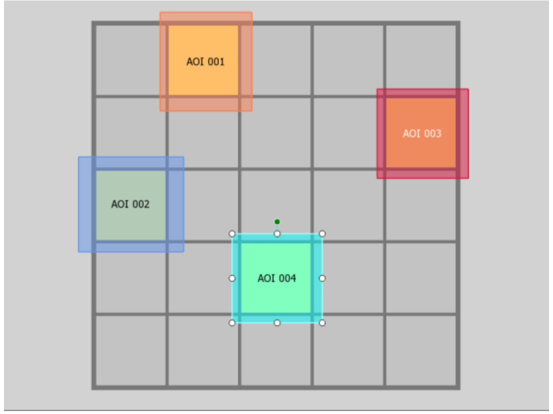
Data analysis

1., Attributes for different eye-movements

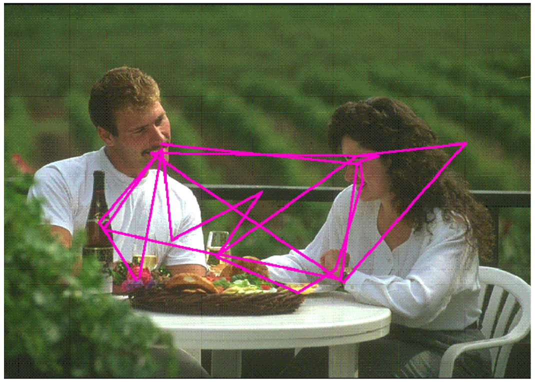
fixation duration, number of fixations, first fixation duration
saccade duration, saccade velocity, saccade lateny, pupil dilation

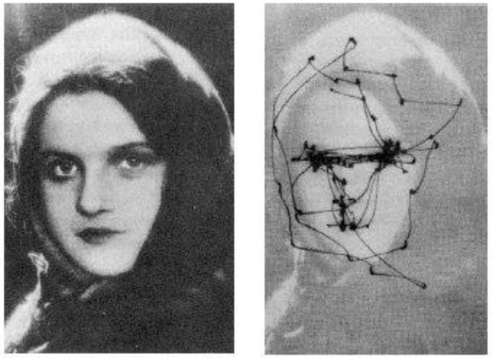
2., Area of Interest analysis (AOI)

Number of fixations, dwell time, first pass time

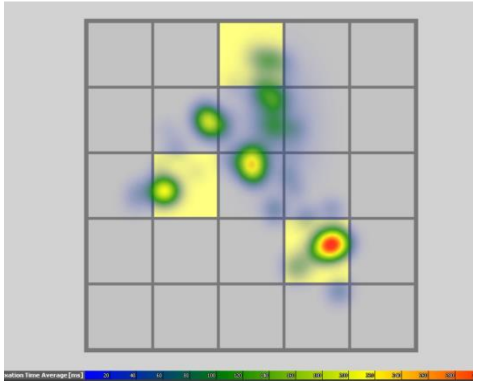


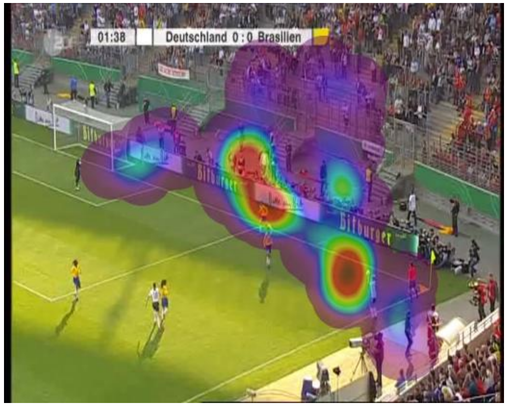
3., Scanpath





4., Heat map



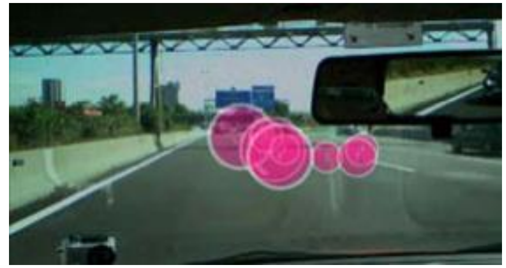


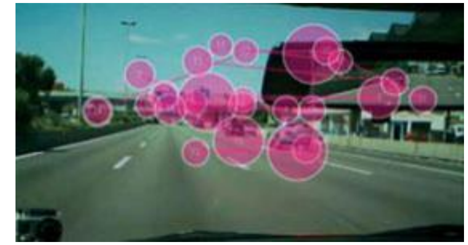
How to use eye-tracking when investigating complex cognitive functions

Example from our lab:attentional flexibility

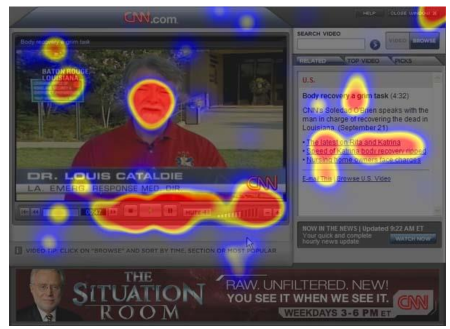
Different applied/academic fields where eye-tracking is used

1. Human Factors
   - Human Computer Interactions (e.g. gace contingent dispalay)
   - Driving studies
   - Visual Inspection

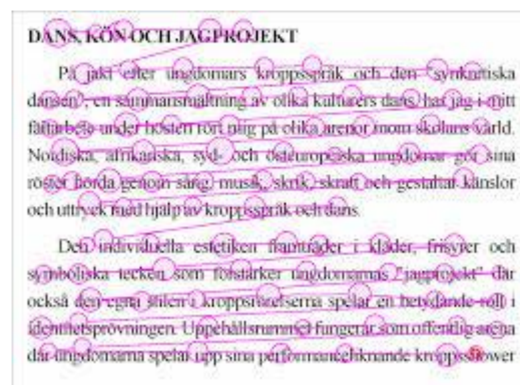




2. Marketing
   - Effectiveness of ads
   - Structure of web pages



3. Psychology and neuroscience
   - Reading studies
   - Visual perception
   - Complex cognitive functions
   - Neuroscience



DANS, KÖN OCH JAGPROJEKT

På jakt efter ungdomars kroppsspråk och den synkretiska dansen, en sammansmältning av olika kulturers dans, har jag i mitt fältarbete under hösten rört mig på olika arenor inom skolans värld. Nordiska, afrikanska, syd- och östeuropeiska ungdomar gör sina röster hörda genom sång, musik, skrik, skratt och gestaltar känslor och uttryck med hjälp av kroppsspråk och dans.

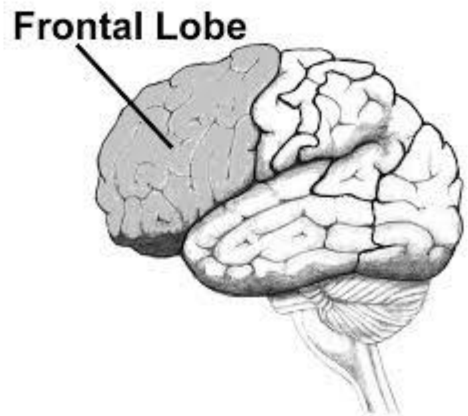
Den individuella estetiken framträder i kläder, frisyer och symboliska tecken som förstärker ungdomarnas "jagprojekt" där också den egna stilen i kroppsrörelserna spelar en betydande roll i identitetsprövningen. Uppehållsrummet fungerar som offentlig arena där ungdomarna spelar upp sina performanceliknande kroppsshower

Attentional set shifting

Attentional set: Attended stimulus dimension in a complex situation, which directs our behaviour.

Attentional set shifting: If our goals change, new stimuus-dimensions (attentional sets) might become relevant.

Example: Buying a new refrigerator – what is important?
→ Energy consumption
→ Price
→ Size



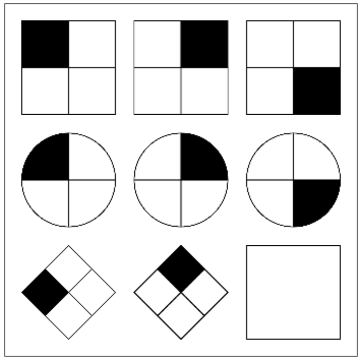
Measures of attentional set shifting

1. Wisconsin Card Sorting Task – a sensible measure of frontal lobe function

http://www.psytoolkit.org/experiment-library/experiment_wcst.html

Perseveration: after aquiring one rule, the participant tends to stick with it:
→ Lesion of the frontal cortex
→ Schizophrenia

2. Raven – IQ test

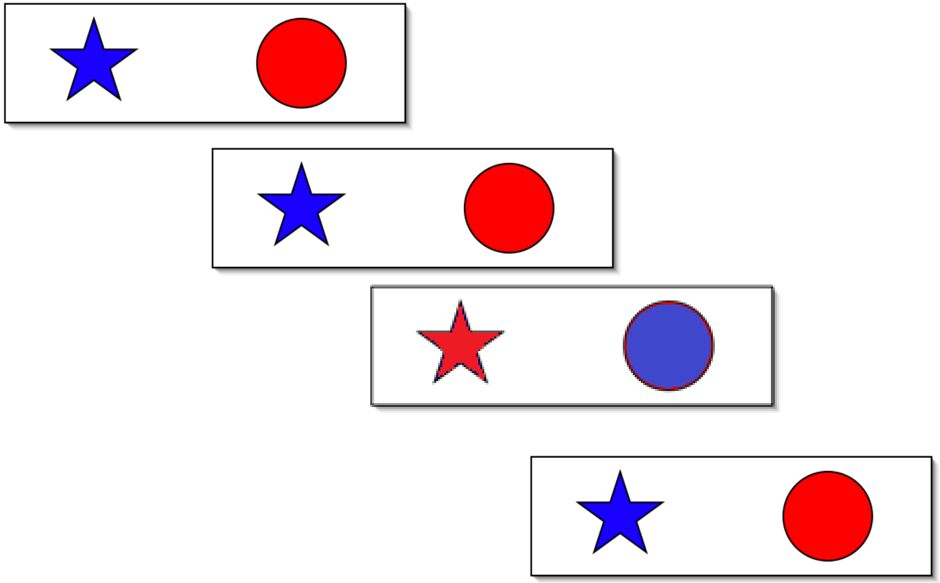


3. Intradimensional/Extradimensional Set Shifting Task

An often used variant of this WCST for measuring attentional set shifting:

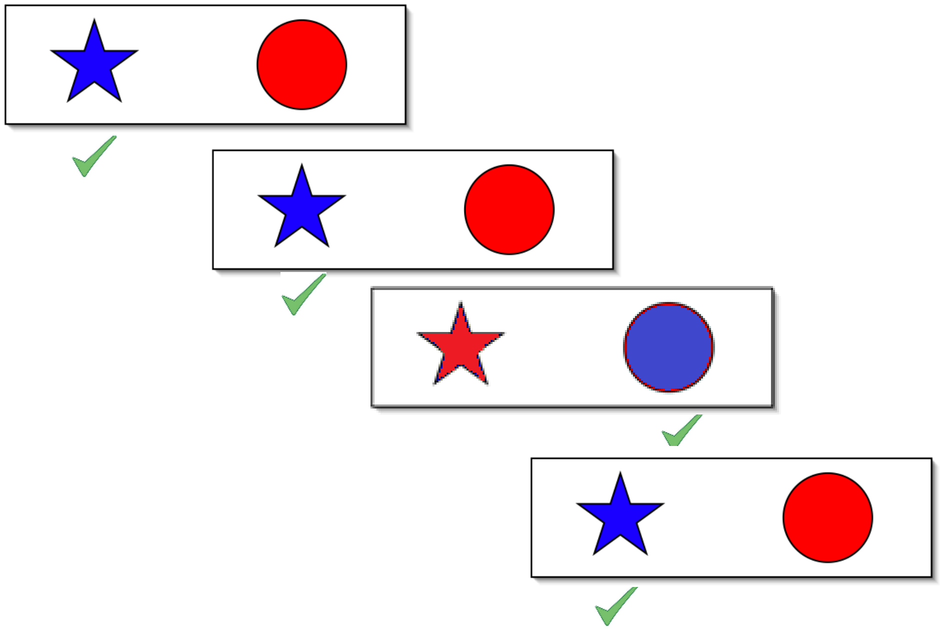
Intradimensional/Extradimensional Set Shifting Task

Basic-task: Which stimulus is rewarded?



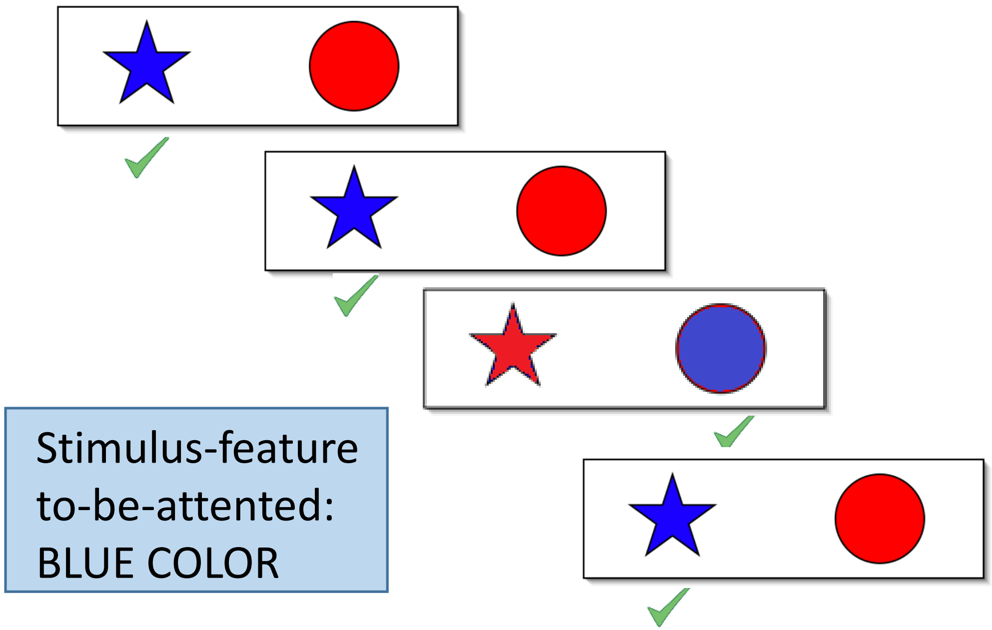
Intradimensional/Extradimensional Set Shifting Task

Basic-task: Which stimulus is rewarded?

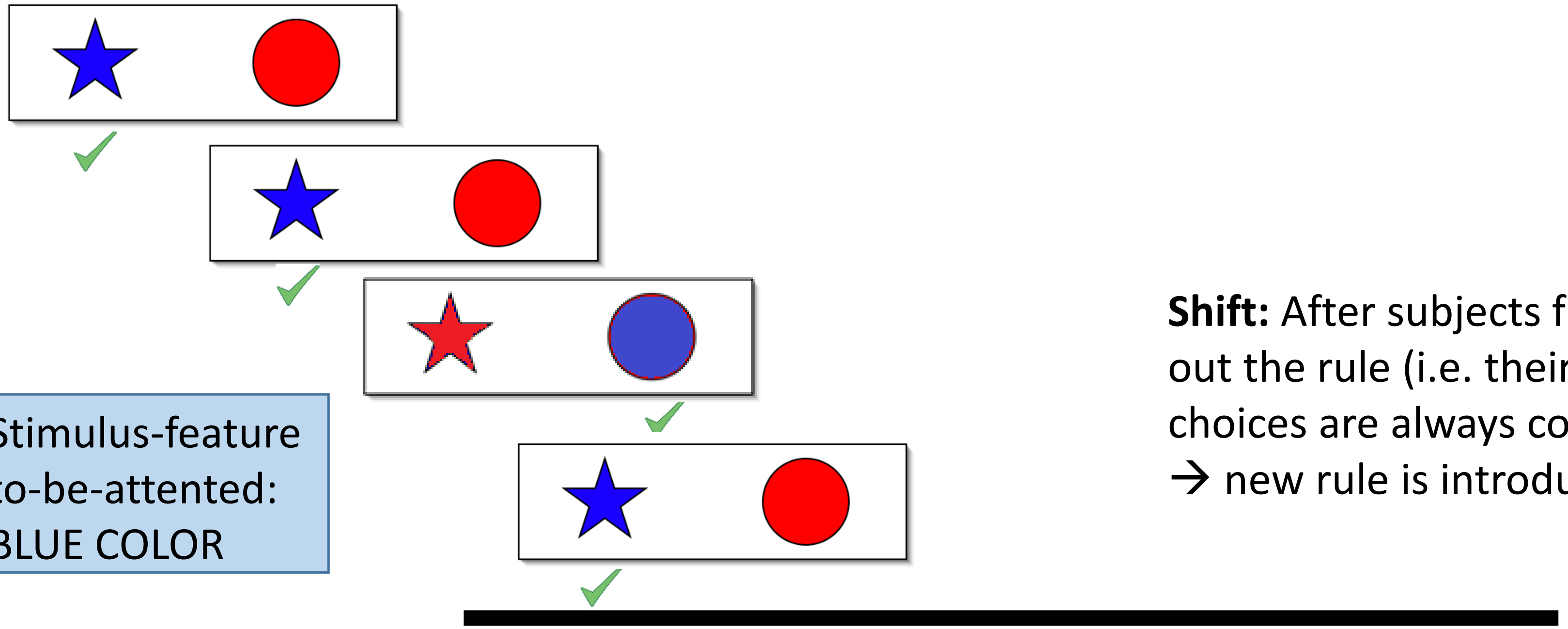


Intradimensional/Extradimensional Set Shifting Task

Basic-task: Which stimulus is rewarded?



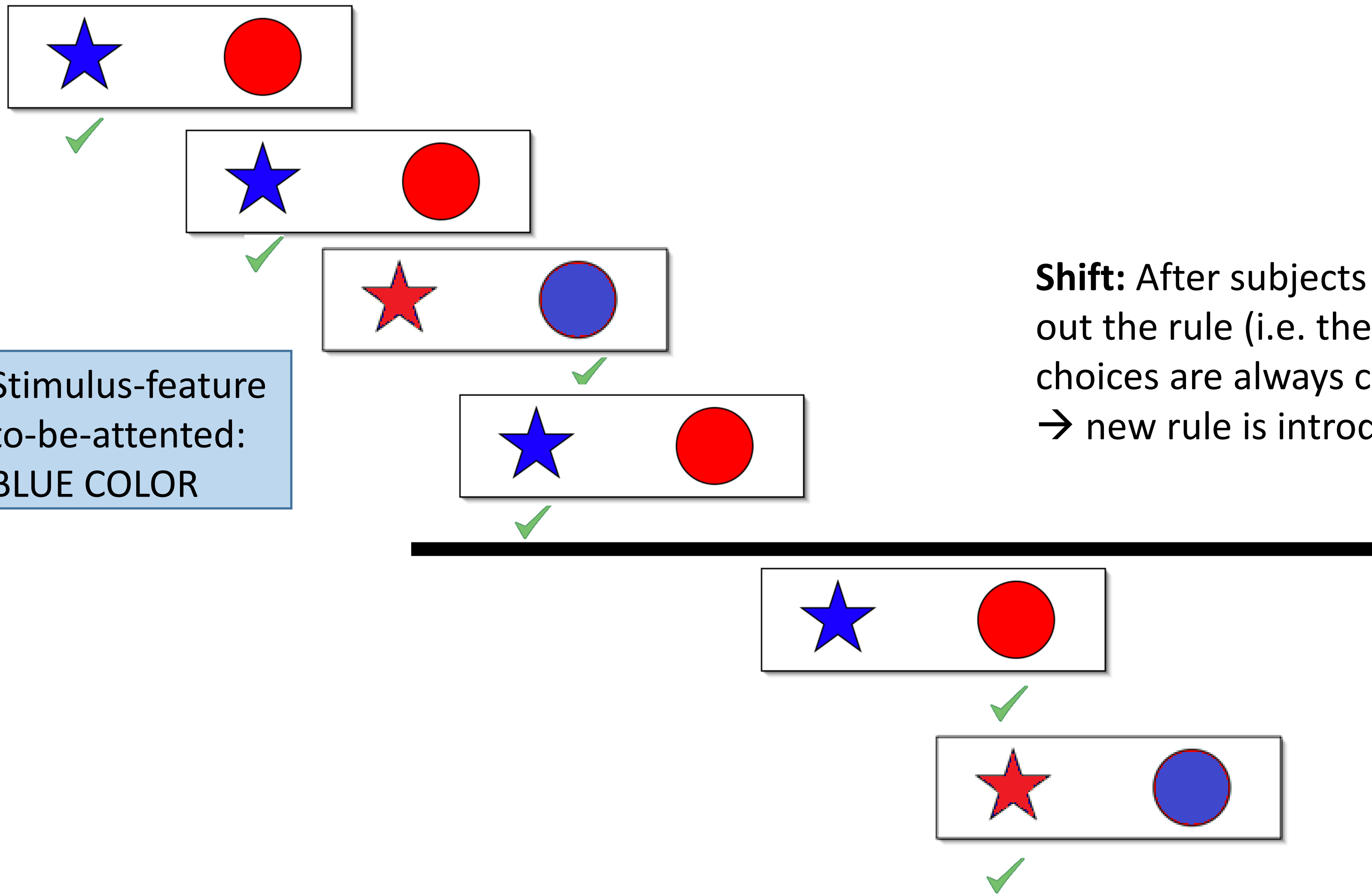
Intradimensional/Extradimensional Set Shifting Task



Stimulus-feature to-be-attented: BLUE COLOR

Shift: After subjects figured out the rule (i.e. their choices are always correct) → new rule is introduced

Intradimensional/Extradimensional Set Shifting Task



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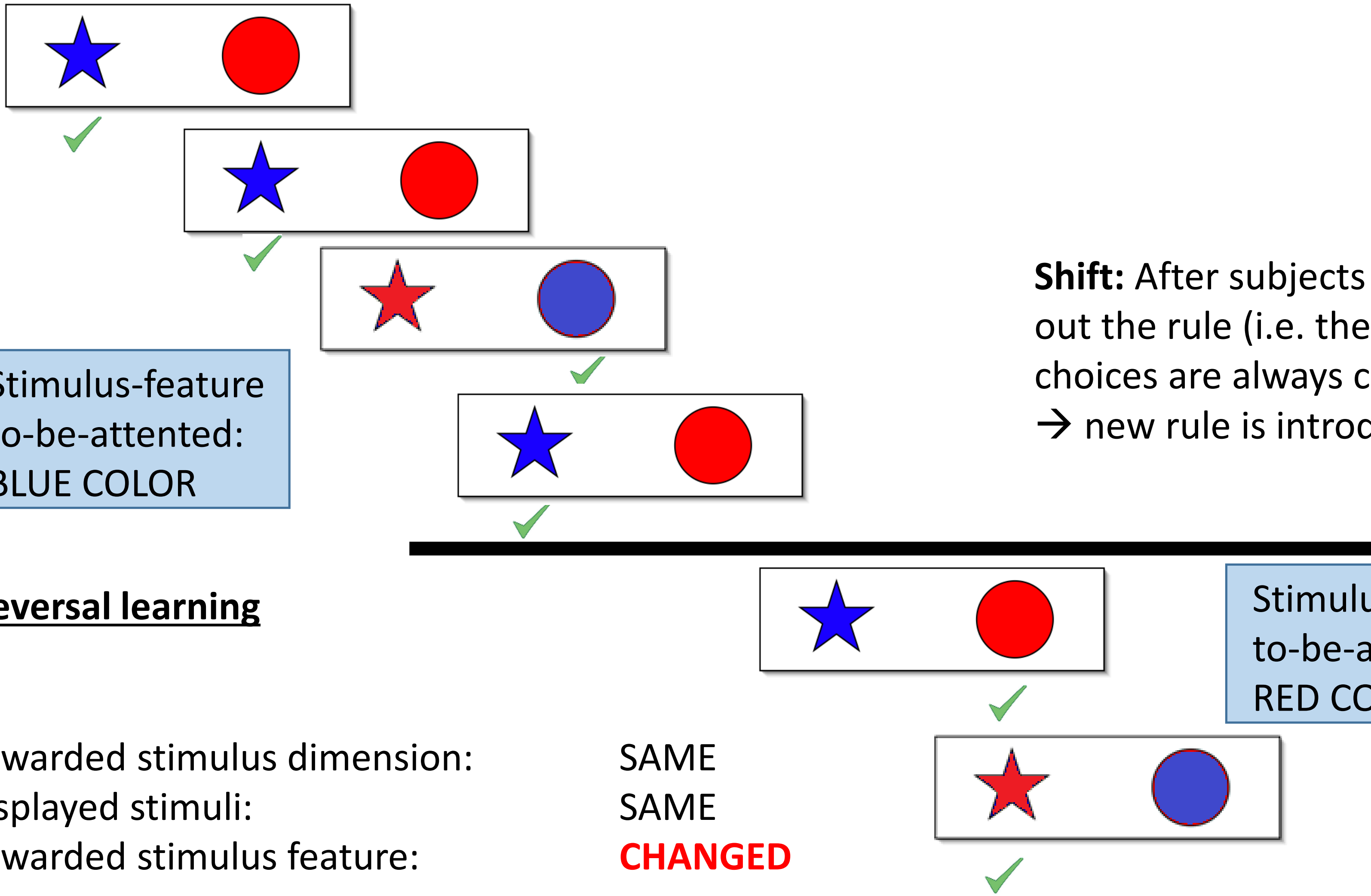


Stimulus-feature to-be-attented: BLUE COLOR

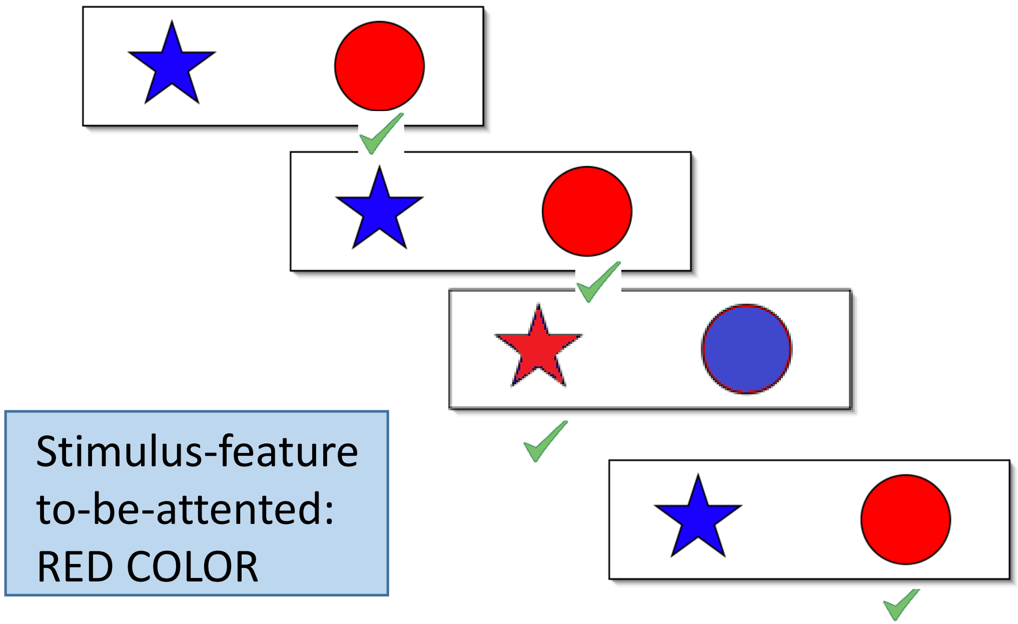
Shift: After subjects figured out the rule (i.e. their choices are always correct) → new rule is introduced

Reversal learning

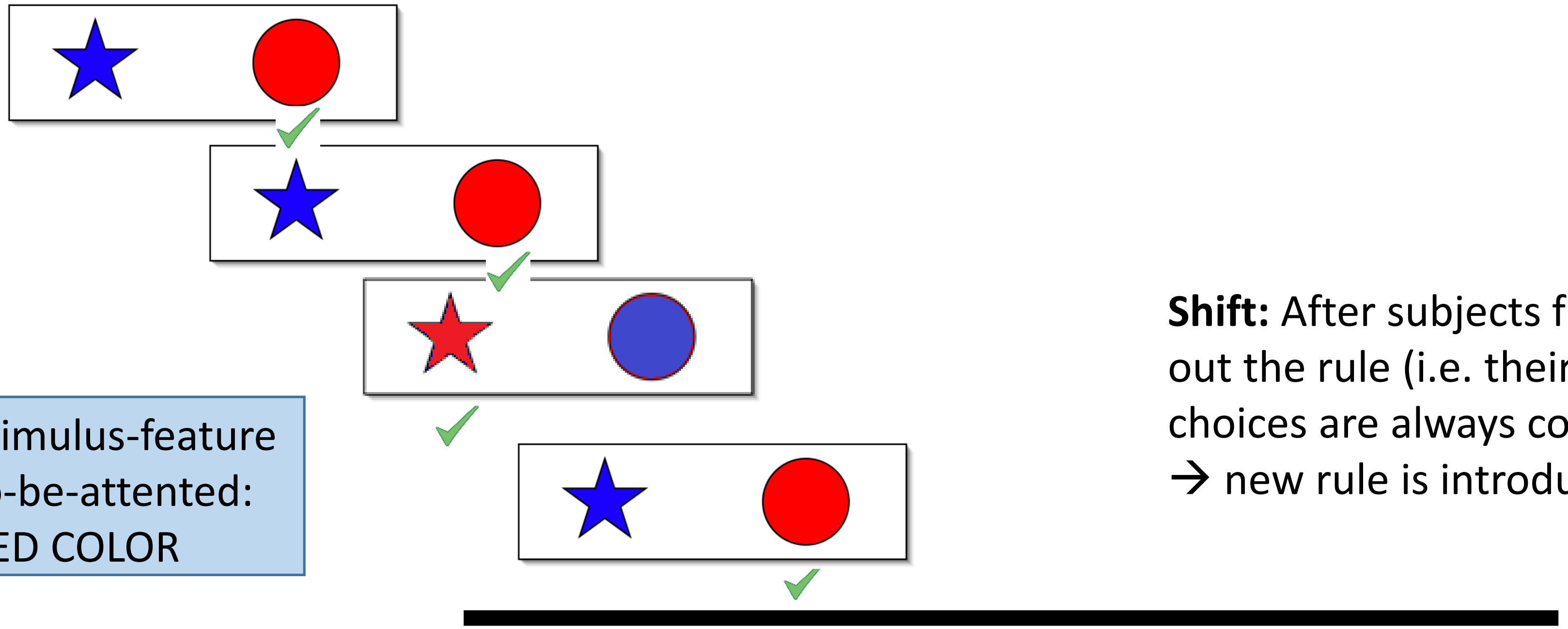
Stimulus-feature to-be-attented: RED COLOR

Rewarded stimulus dimension: SAME
Displayed stimuli: SAME
Rewarded stimulus feature: **CHANGED**

Intradimensional/Extradimensional Set Shifting Task



Intradimensional/Extradimensional Set Shifting Task



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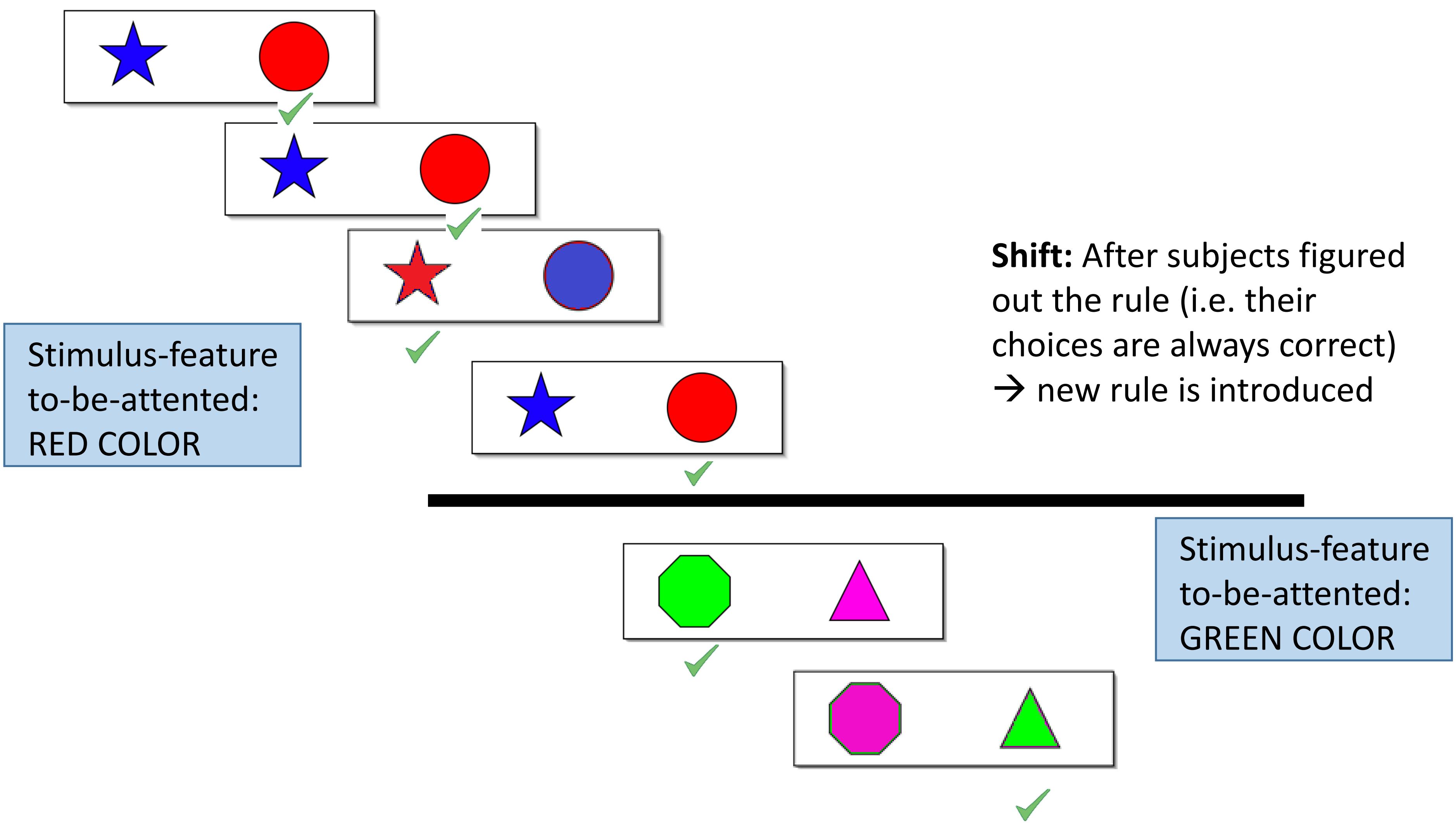
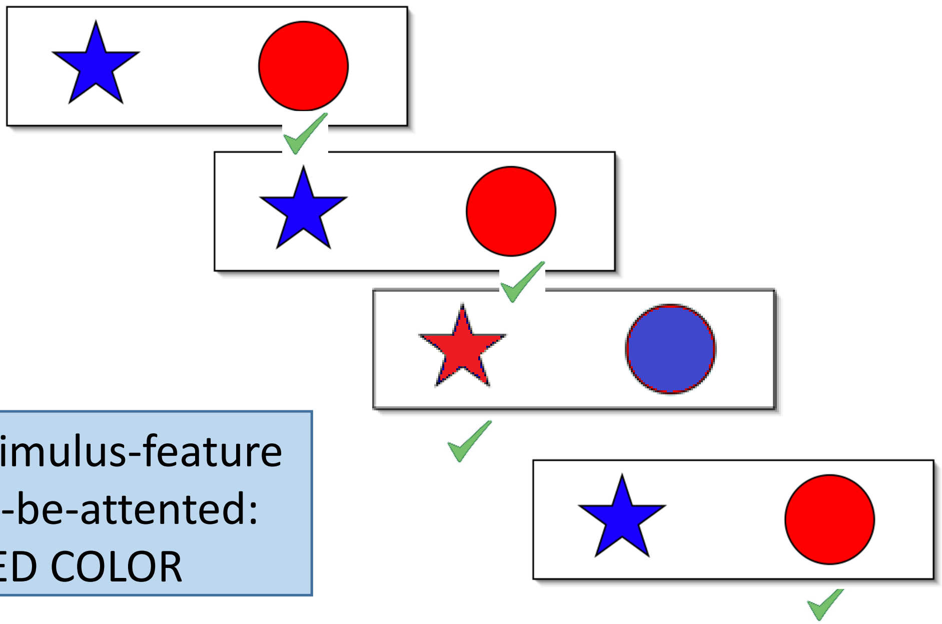


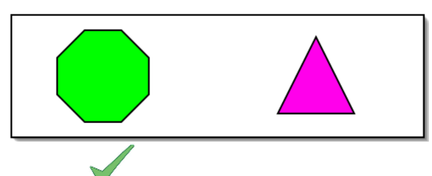
Intradimensional/Extradimensional Set Shifting Task

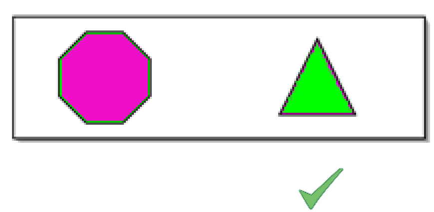


Stimulus-feature to-be-attented: RED COLOR

Shift: After subjects figured out the rule (i.e. their choices are always correct) → new rule is introduced

Intradimensional shift (IDS)

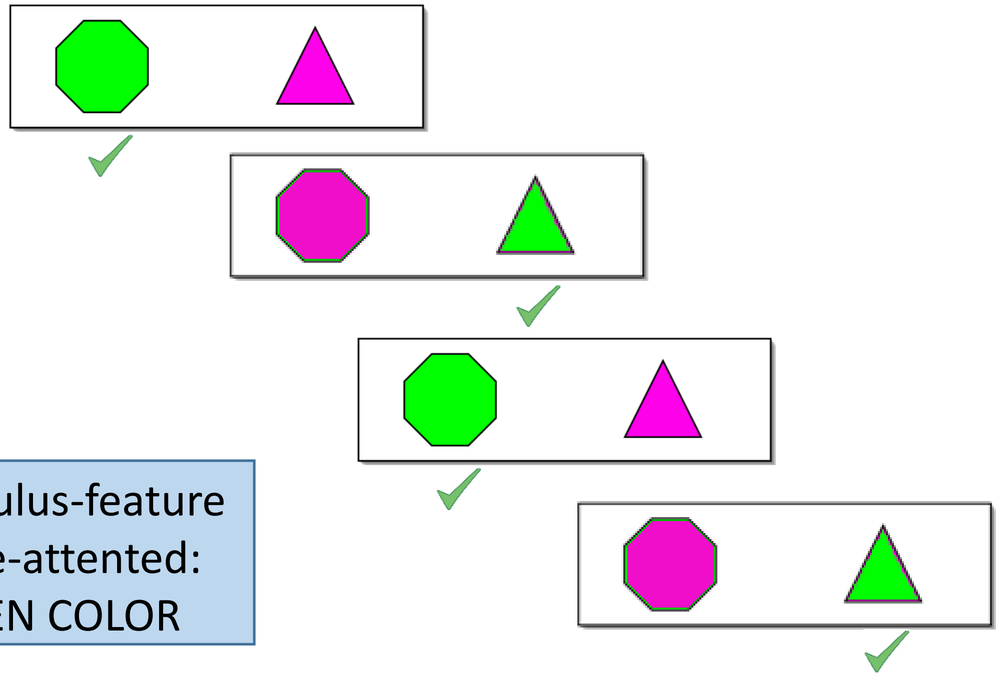




Stimulus-feature to-be-attented: GREEN COLOR

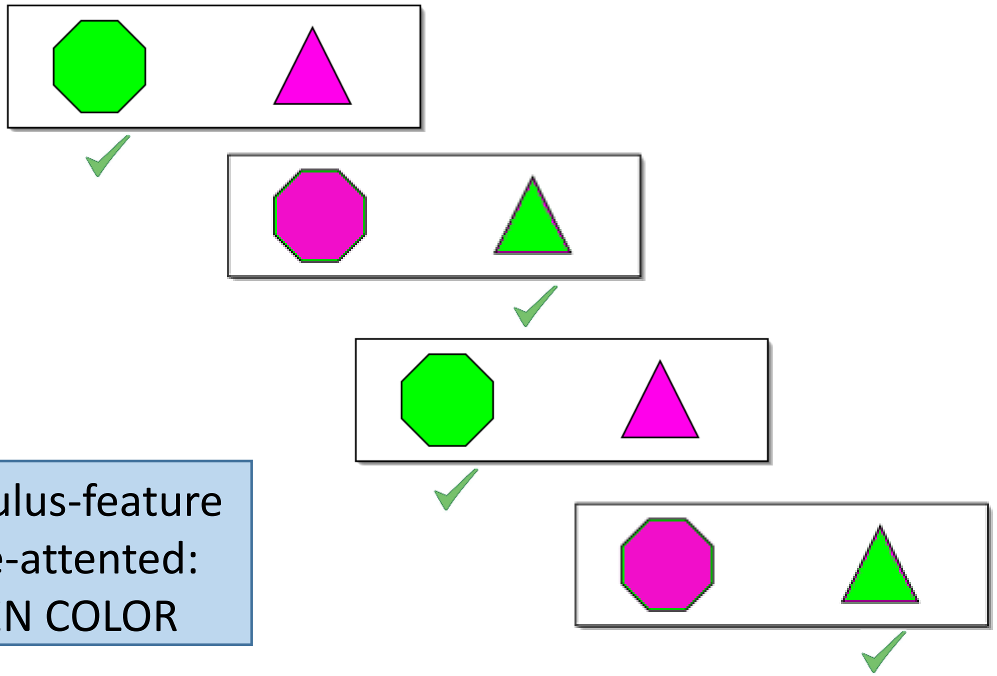
Rewarded stimulus dimension: SAME
Displayed stimuli: CHANGED
Rewarded stimulus feature: CHANGED

Intradimensional/Extradimensional Set Shifting Task



Stimulus-feature to-be-attented: GREEN COLOR

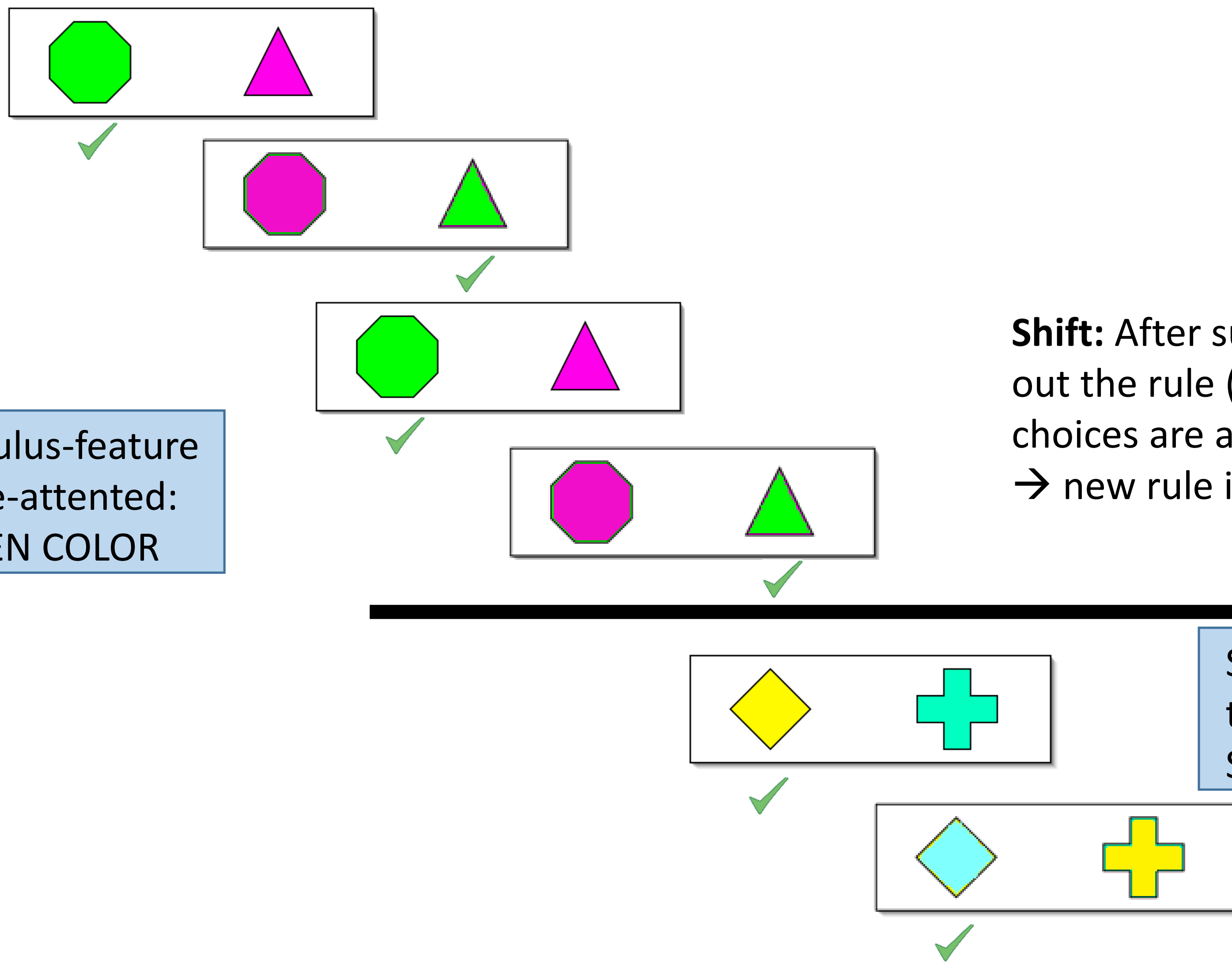
Intradimensional/Extradimensional Set Shifting Task



Stimulus-feature to-be-attented: GREEN COLOR

Shift: After subjects figured out the rule (i.e. their choices are always correct) → new rule is introduced

Intradimensional/Extradimensional Set Shifting Task

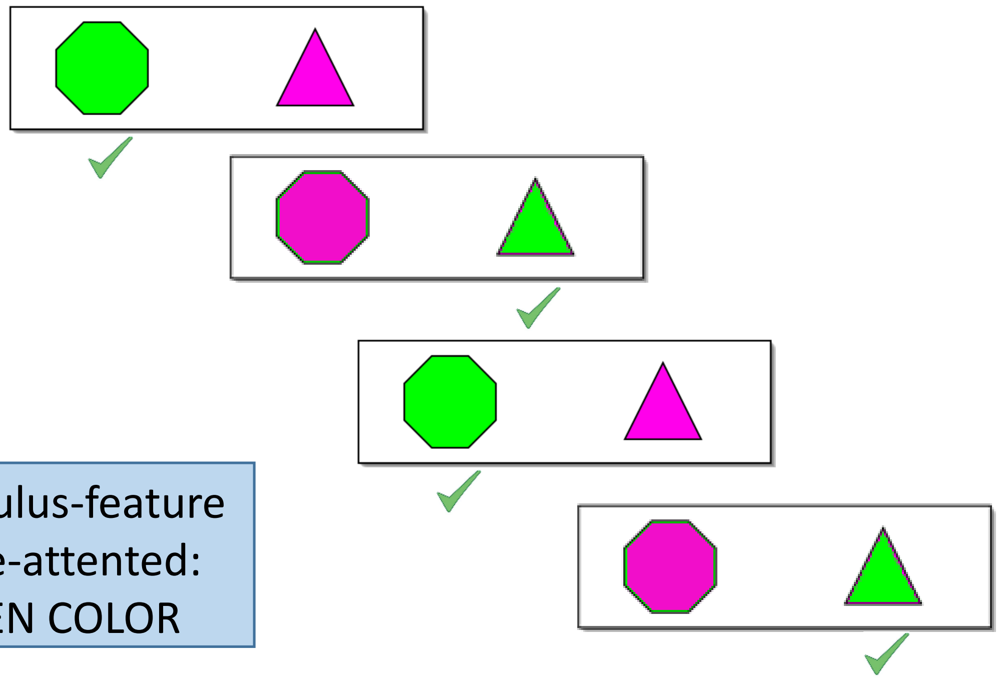


Stimulus-feature
to-be-attented:
GREEN COLOR

Shift: After subjects figured out the rule (i.e. their choices are always correct) → new rule is introduced

Stimulus-feature
to-be-attented:
SQUARE FORM

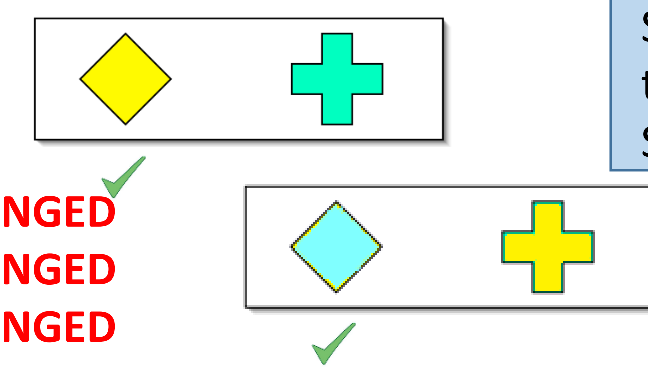
Intradimensional/Extradimensional Set Shifting Task



Stimulus-feature to-be-attented: GREEN COLOR

Shift: After subjects figured out the rule (i.e. their choices are always correct) → new rule is introduced

<u>Extradimensional shift (EDS)</u>



Stimulus-feature to-be-attented: SQUARE FORM

Rewarded stimulus dimension: **CHANGED**
Displayed stimuli: **CHANGED**
Rewarded stimulus feature: **CHANGED**

Intradimensional/Extradimensional Set Shifting Task

Reversal learning

Rewarded stimulus dimension:	SAME
Displayed stimuli:	SAME
Rewarded stimulus feature:	**CHANGED**

Intradimensional shift (IDS)

Rewarded stimulus dimension:	SAME
Displayed stimuli:	**CHANGED**
Rewarded stimulus feature:	**CHANGED**

Extradimensional shift (EDS)

Rewarded stimulus dimension:	**CHANGED**
Displayed stimuli:	**CHANGED**
Rewarded stimulus feature:	**CHANGED**

Intradimensional/Extradimensional Set Shifting Task

Reversal learning

Rewarded stimulus dimension:	SAME
Displayed stimuli:	SAME
Rewarded stimulus feature:	**CHANGED**

Intradimensional shift (IDS)

Rewarded stimulus dimension:	SAME
Displayed stimuli:	**CHANGED**
Rewarded stimulus feature:	**CHANGED**

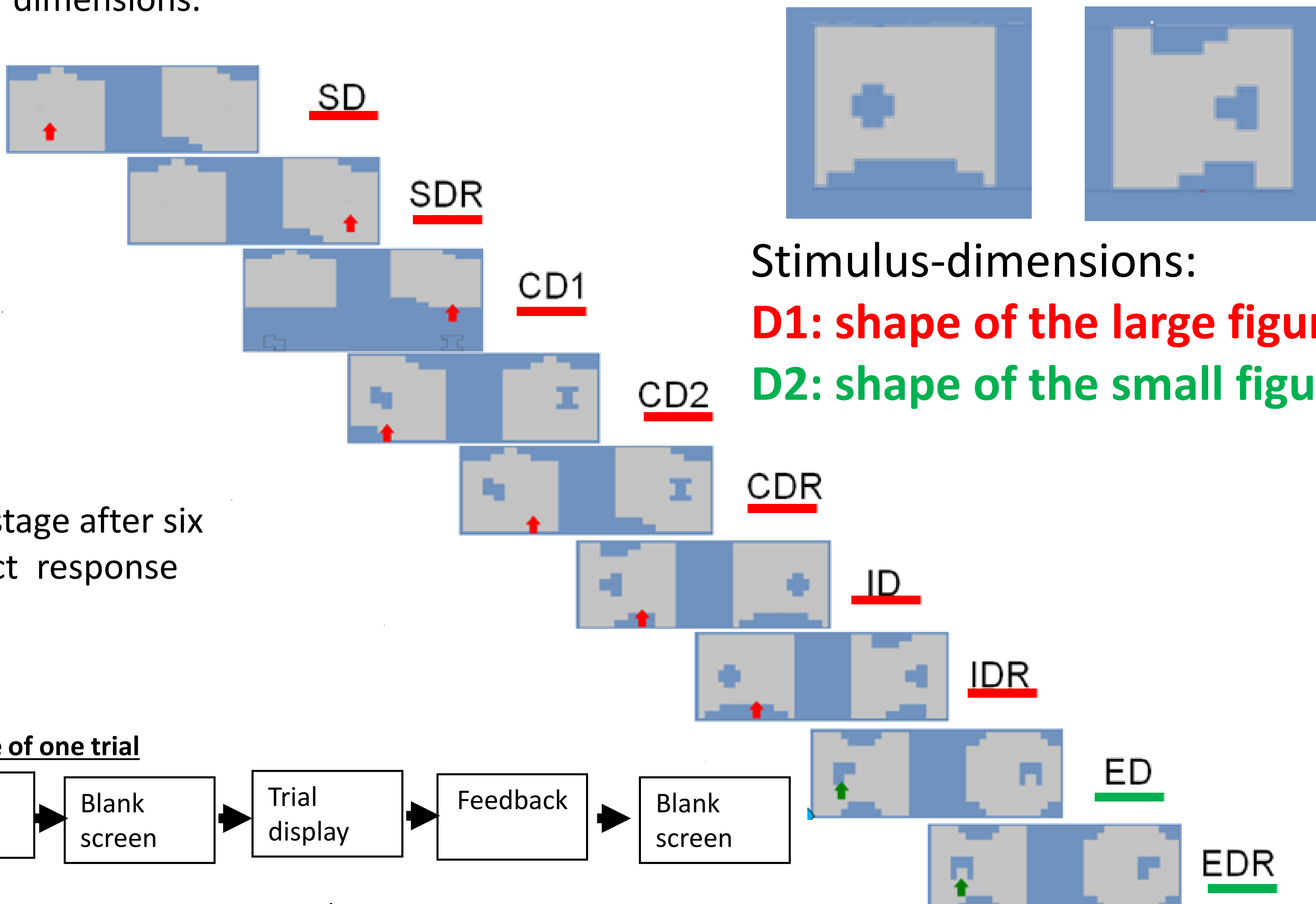
Extradimensional shift (EDS)

Rewarded stimulus dimension:	**CHANGED**
Displayed stimuli:	**CHANGED**
Rewarded stimulus feature:	**CHANGED**

Most difficult shift:
Mild to severe deficit in several neurological and psychiatric population

The eye-IED task

Adaptation to eye-tracking: spatially separating the different stimulus dimensions.



Stimulus-dimensions:

D1: shape of the large figure

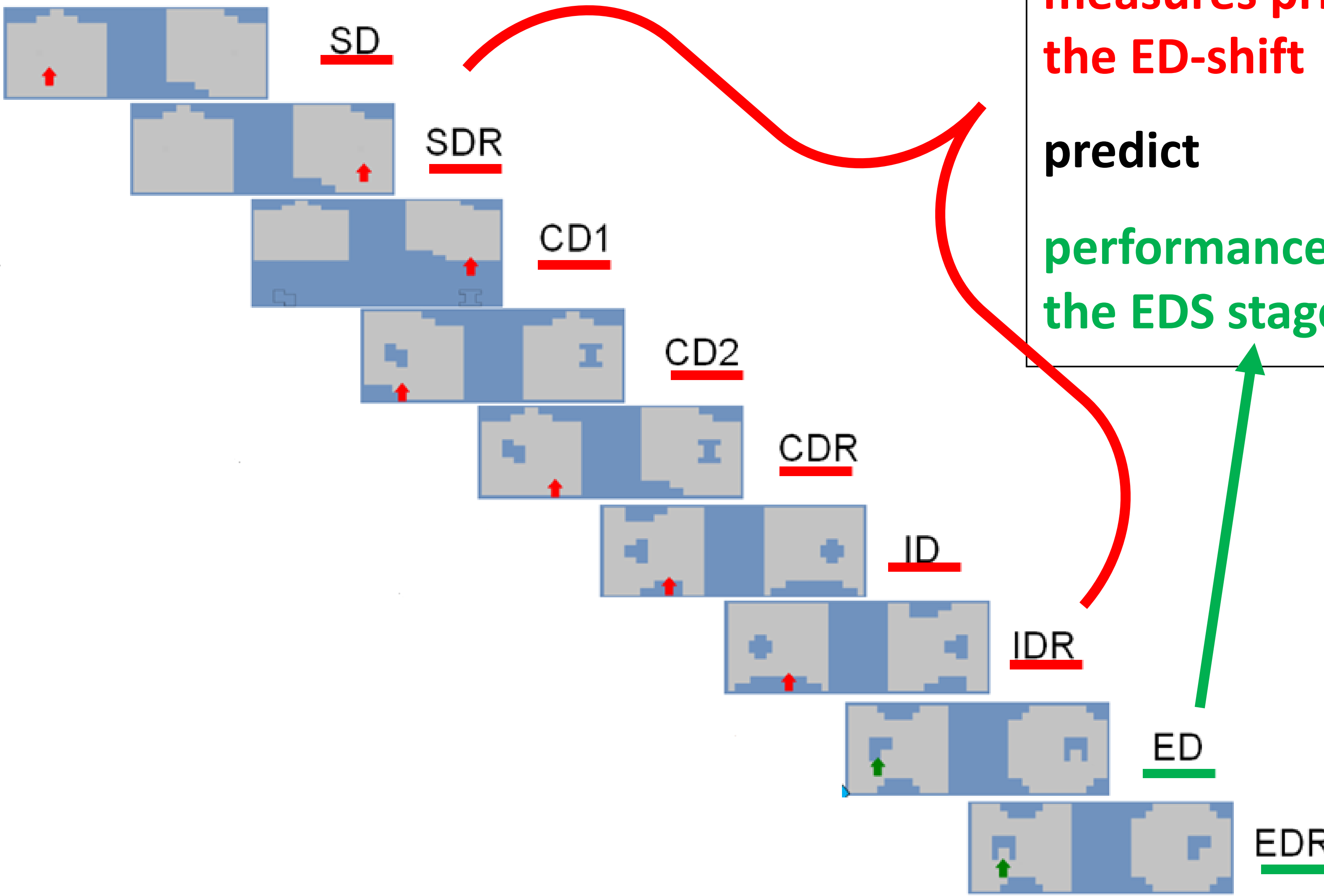
D2: shape of the small figure

New stage after six correct response

Sequence of one trial

Fixation cross	Blank screen	Trial display	Feedback	Blank screen
2000 msec	500 msec	Until response	1000 msec	500 msec

The eye-IED task



Hypothesis:

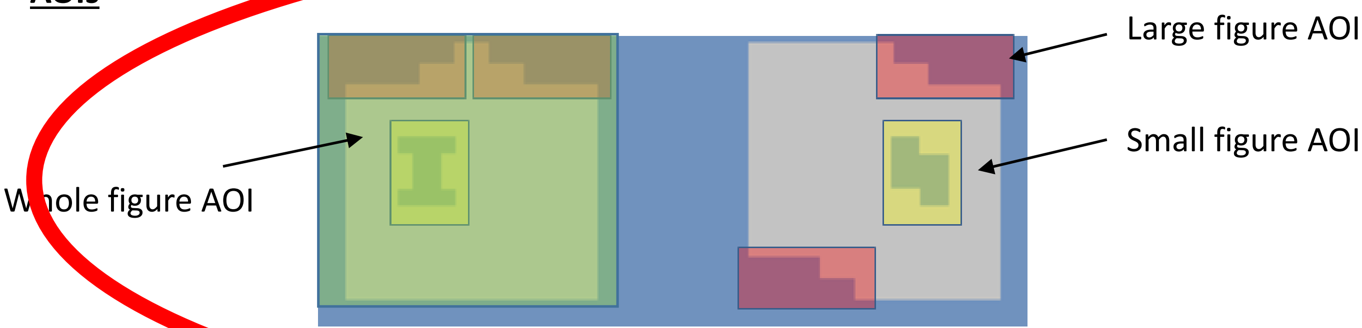
Eye-tracker measures prior to the ED-shift

predict

performance in the EDS stage

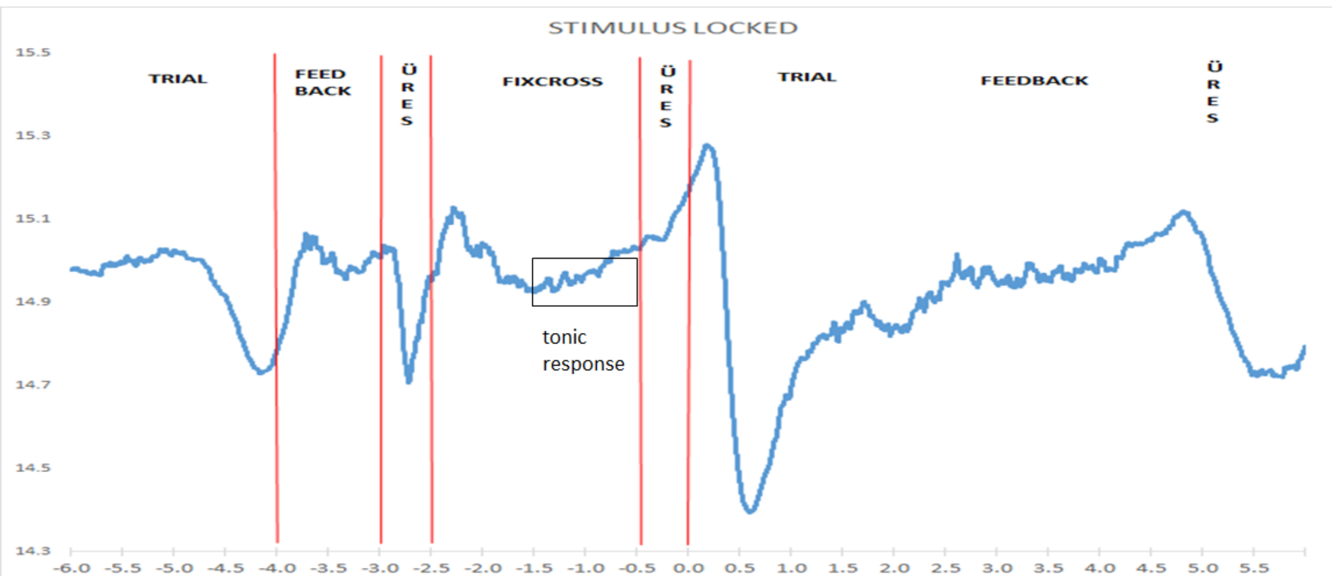
The eye-IED task - measures

AOIs



- Dwell times for the small/large AOIs (dotted frame)
- Corrected dwell times for the different AOIs: dwell times for the small large AOIs, divided by the dwell time for the whole figure

Pupil dilation



- Baseline pupil dilation indexing tonic activity of the LC/NE system

Study participants

<u>Normal population - students</u>

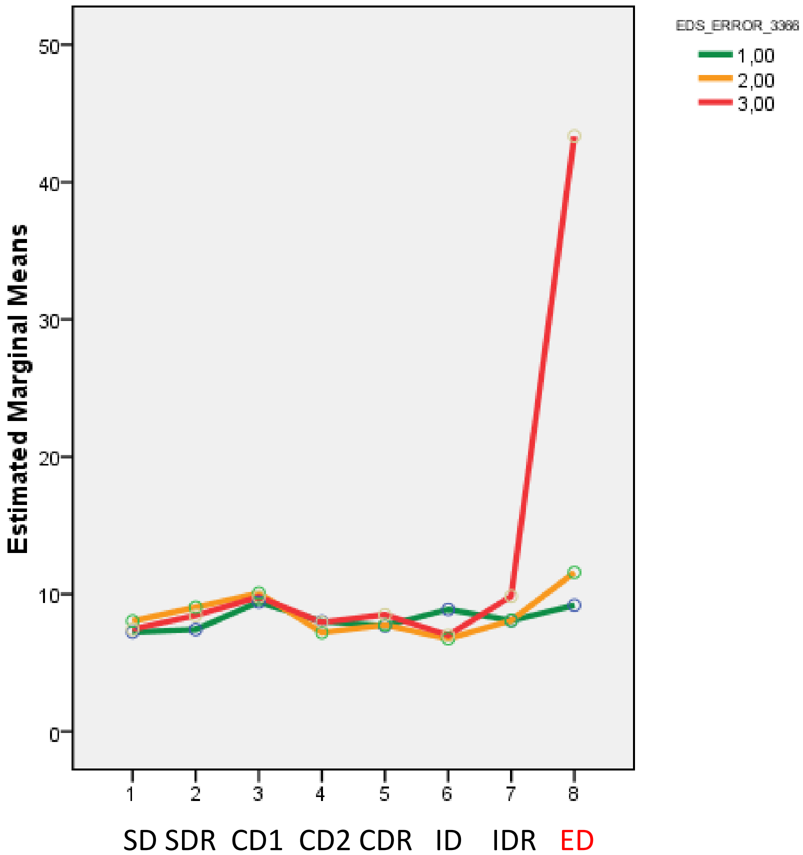
N=70

3 groups:

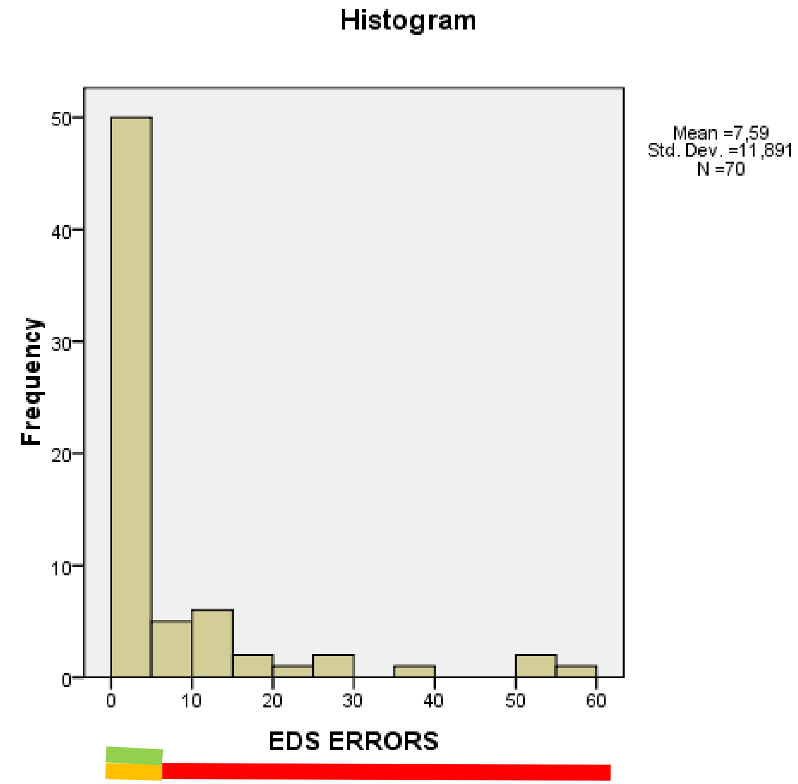
- Good ED performance: Errors in ED stage less than 3 (below the 33th percentile) - N=26
- Medium ED Performance: 3 or 4 errors in ED stage 3 (33th-66th percentile) - N=24
- Bad ED performance: Errors in ED stage more than 9 (above 66th percentile) – N=20

Behavioral results

Task performance



Distribution of ED errors

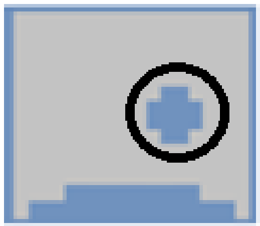


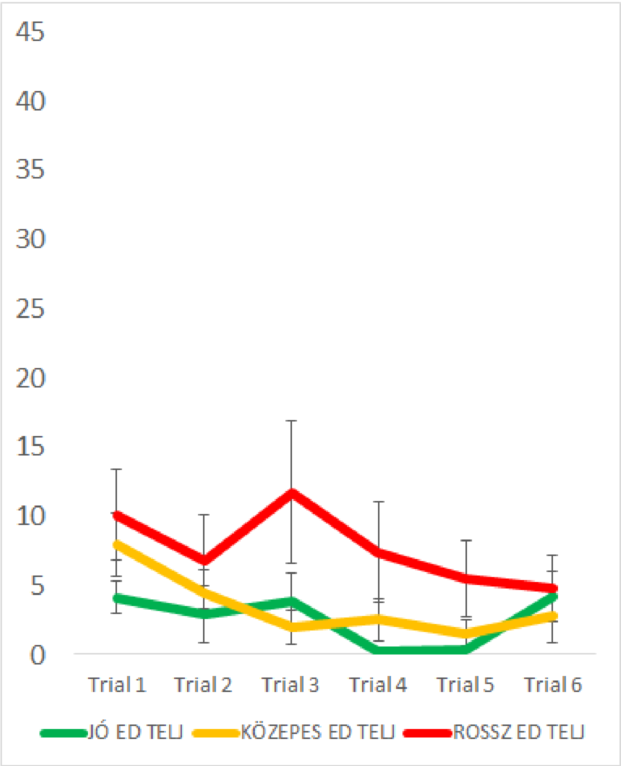
AOI-analysis I.

Dwell times for the first six trials of the ED stage

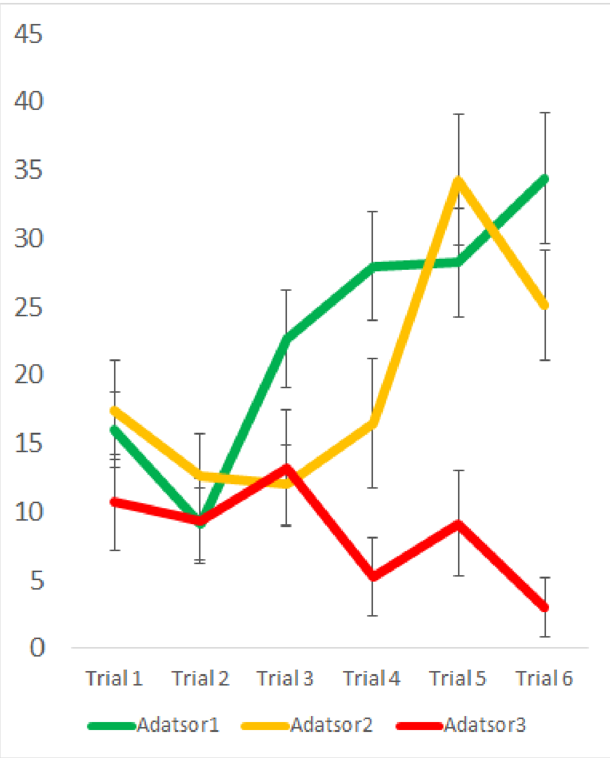
Dwell times –
Large figure AOI

Dwell times –
Small figure AOI





AOI main effect: F(2,73)=2.5, p=.0.08

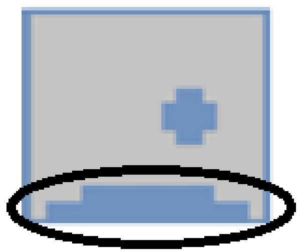


AOI main effect: F(2,73)=7.8, p=.001

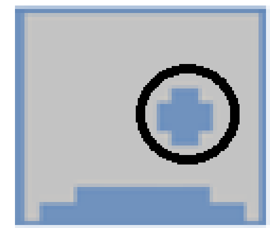
AOI-analysis II.

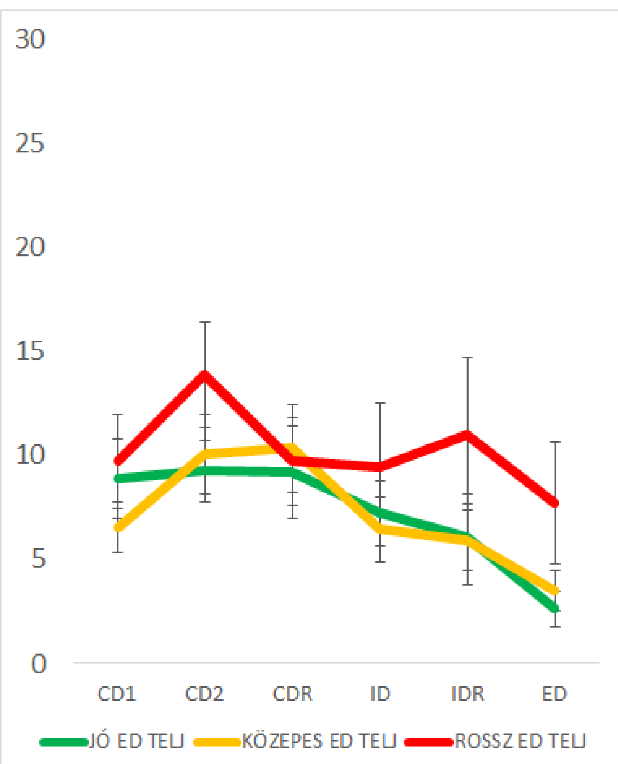
Dwell time average for the stages preceeding the ED stage

Dwell times –
Large figure AOI

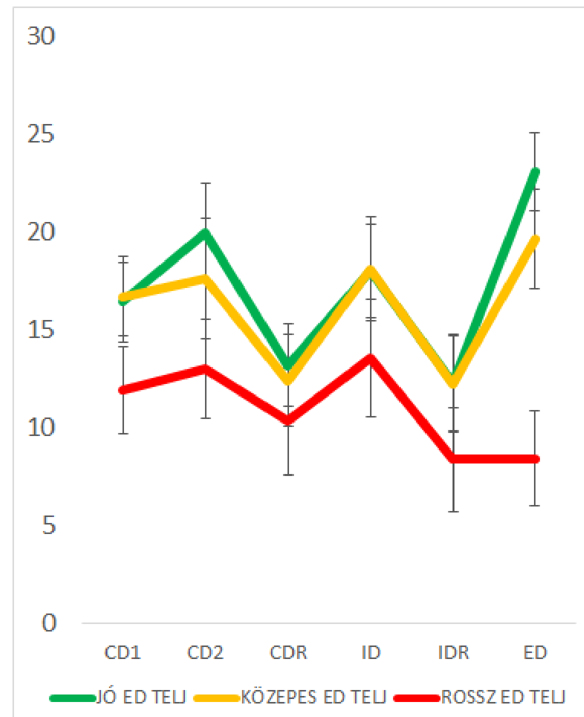


Dwell times –
Small figure AOI





AOI main effect: F(2,73)=1.3, p=.24



AOI main effect: F(2,73)=3.3, p=.03

Conclusions

Attentional patternis before the extradimensional shift stage predict succesfull attentional set shifting.

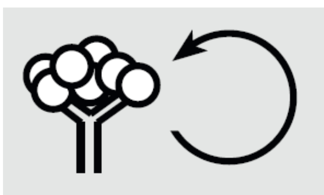
Exploring basic brain networks using eye-tracking

Should I stay or should I go? The exploration-exploitation dilemma

Exploiting actions associated with current rewards. ⟷ **Exploring** the environment for novel, potentially more rewarding options.

Dilemma

Rewards associated with exploration are uncertain – they can be either larger or smaller than the rewards associated with exploitation.



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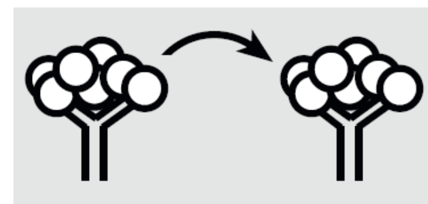
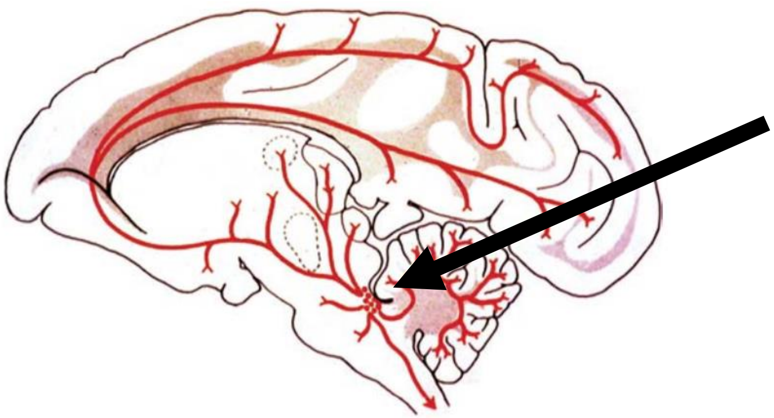


Neural systems associated with the exploitation-exploration tradeoff

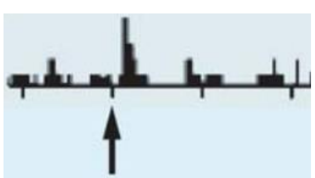
Noradrenaline – LC-NE system



Locus coeruleus

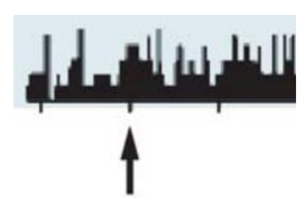
Exploitation - phasic mode of the LC:

- Low baseline firing with stimulus/response related burst
- Steady-state performance in a known task
- High levels of task performance



Exploration - tonic mode og the LC:

- High baseline firing with no bursts
- Exploring the environment without clear task goals
- Low level, error prone task performance



e.g. Aston-Jones & Cohen, 2005; Bouret & Sara 2005

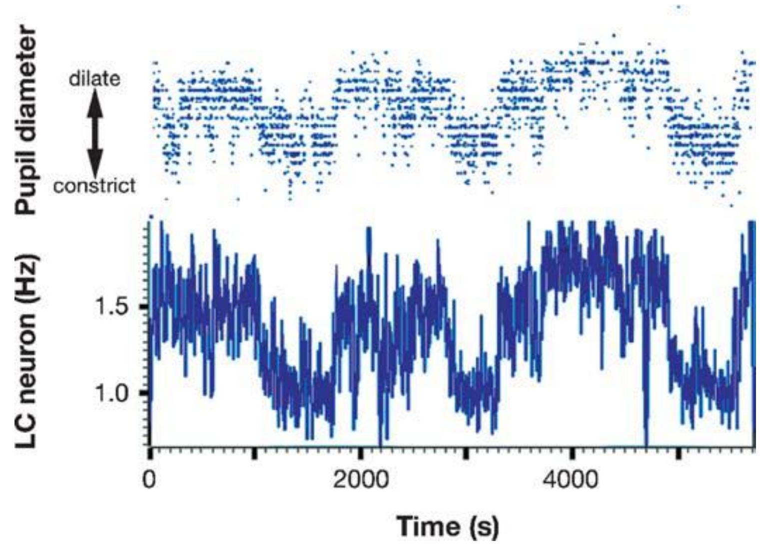
Neural systems associated with the exploitation-exploration tradeoff

Noradrenaline – LC-NE system

→ LC activity strongly correlates with pupil diameter

Aston-Jones & Cohen, 2005

Murphy et al., 2014



Studies with human subjects

High correlation between LC activity and pupil diameter

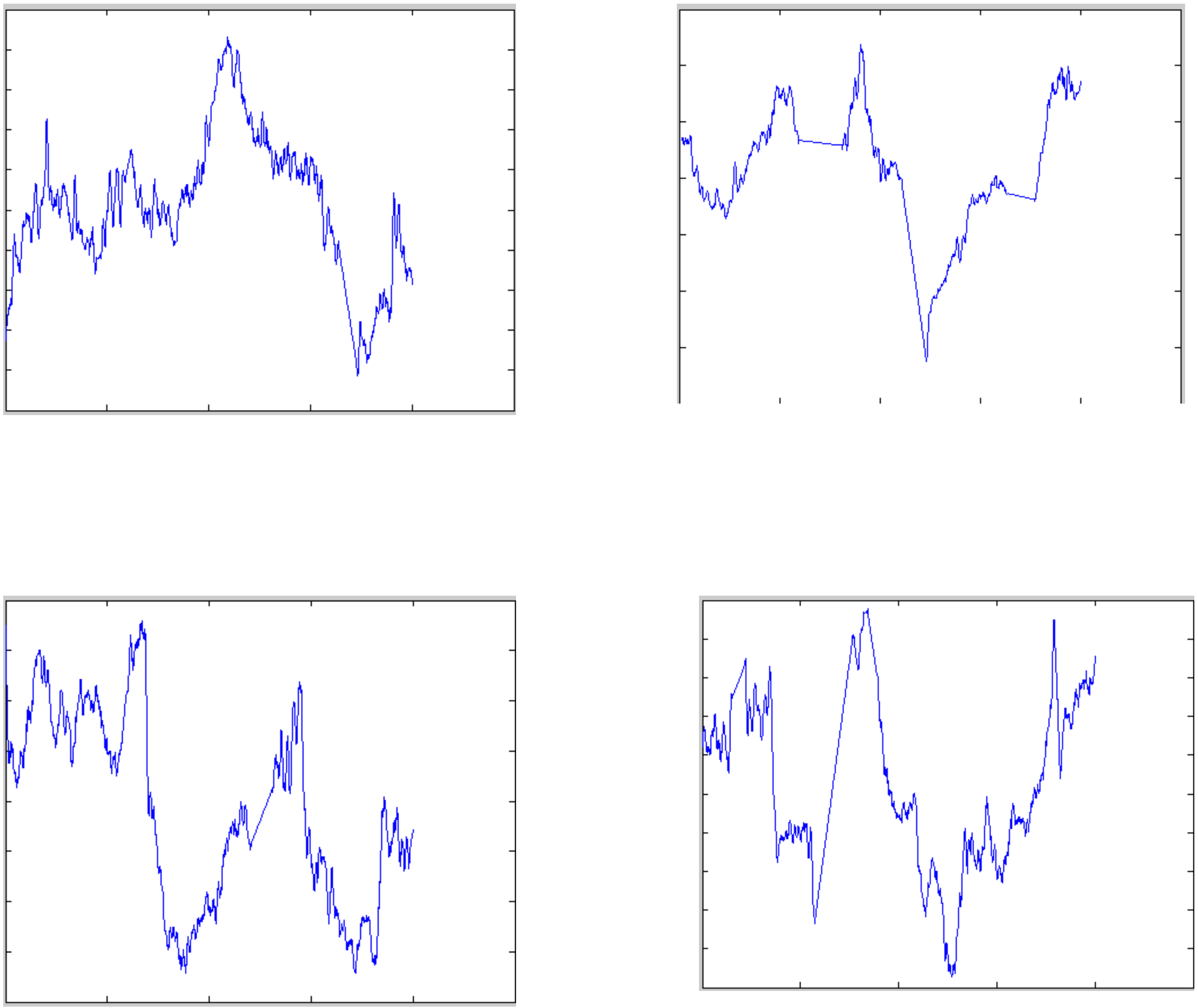
Phasic changes in pupil dilation predict hit rate, steady-state performance, mental effort, WM performance.

Tonic changes in pupil dilation predict erroneous performance

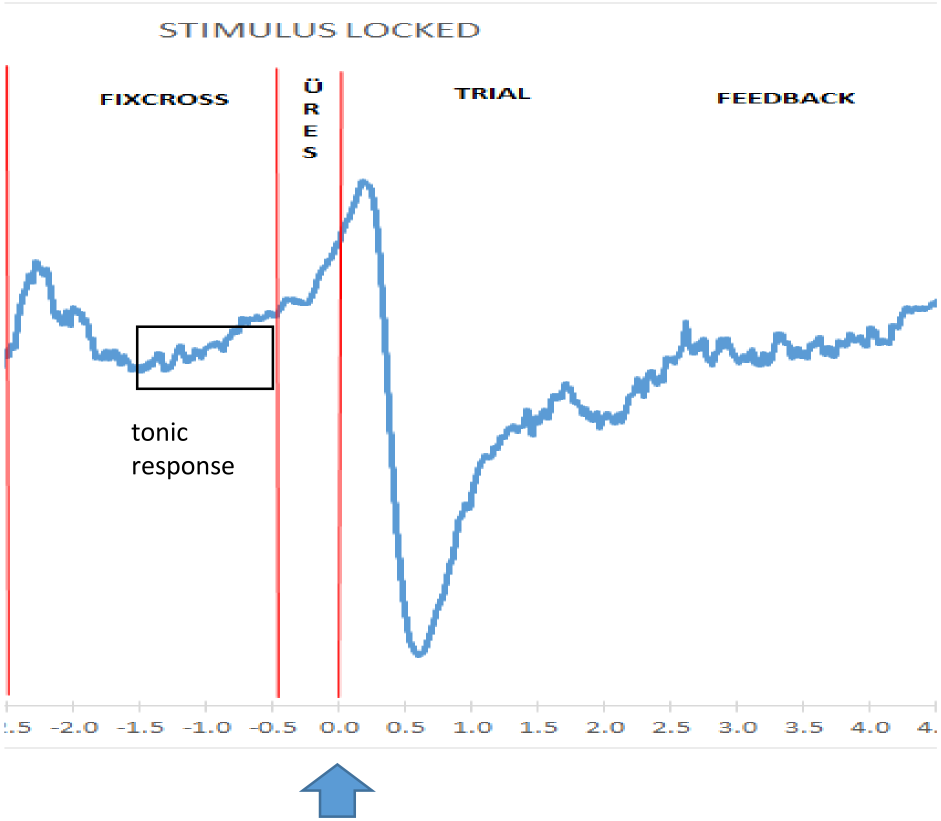
Gilzenrat et al., 2010; Unsworth & Robinson, 2015; Murphy et al, 2011

HYPOTHESIS: Attentional set shifting → exploration → tonic activation

Pupil diameter – individual trials



Stimulus locked averaged pupil diamater



STIMULUS PRESENTED

Sequence of one trial

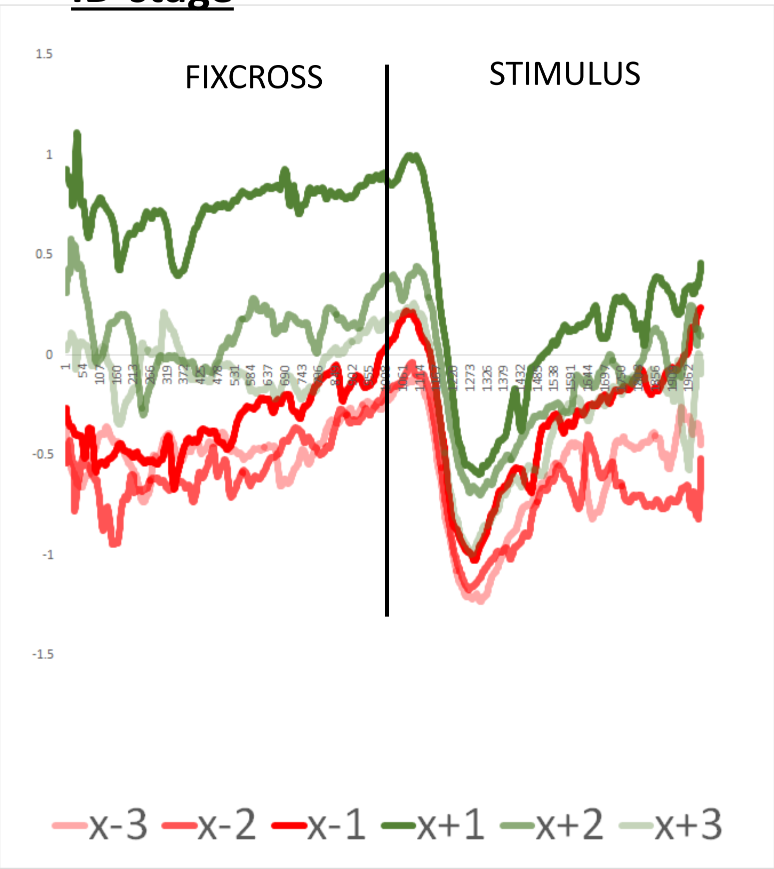
Fixation cross	Blank screen	Trial display	Feedback	Blank screen
2000 msec	500 msec	Until response	1000 msec	500 msec

‚ÜRES' (hu) = blank

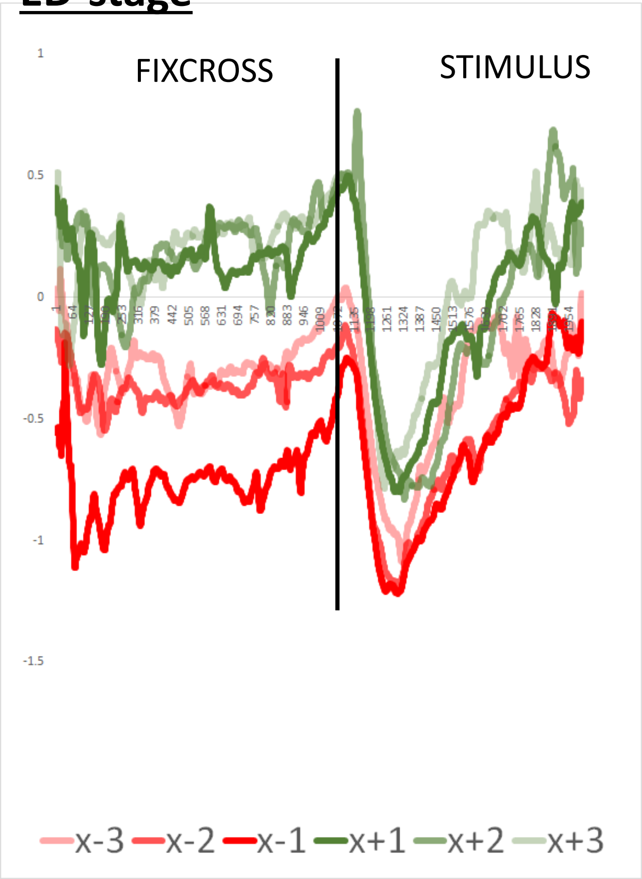
Pupil diameter before and after a switch

Pretrial pupil diameter indexing tonic activity of the LC/NE system BEFORE and AFTER switch

<u>ID-stage</u>

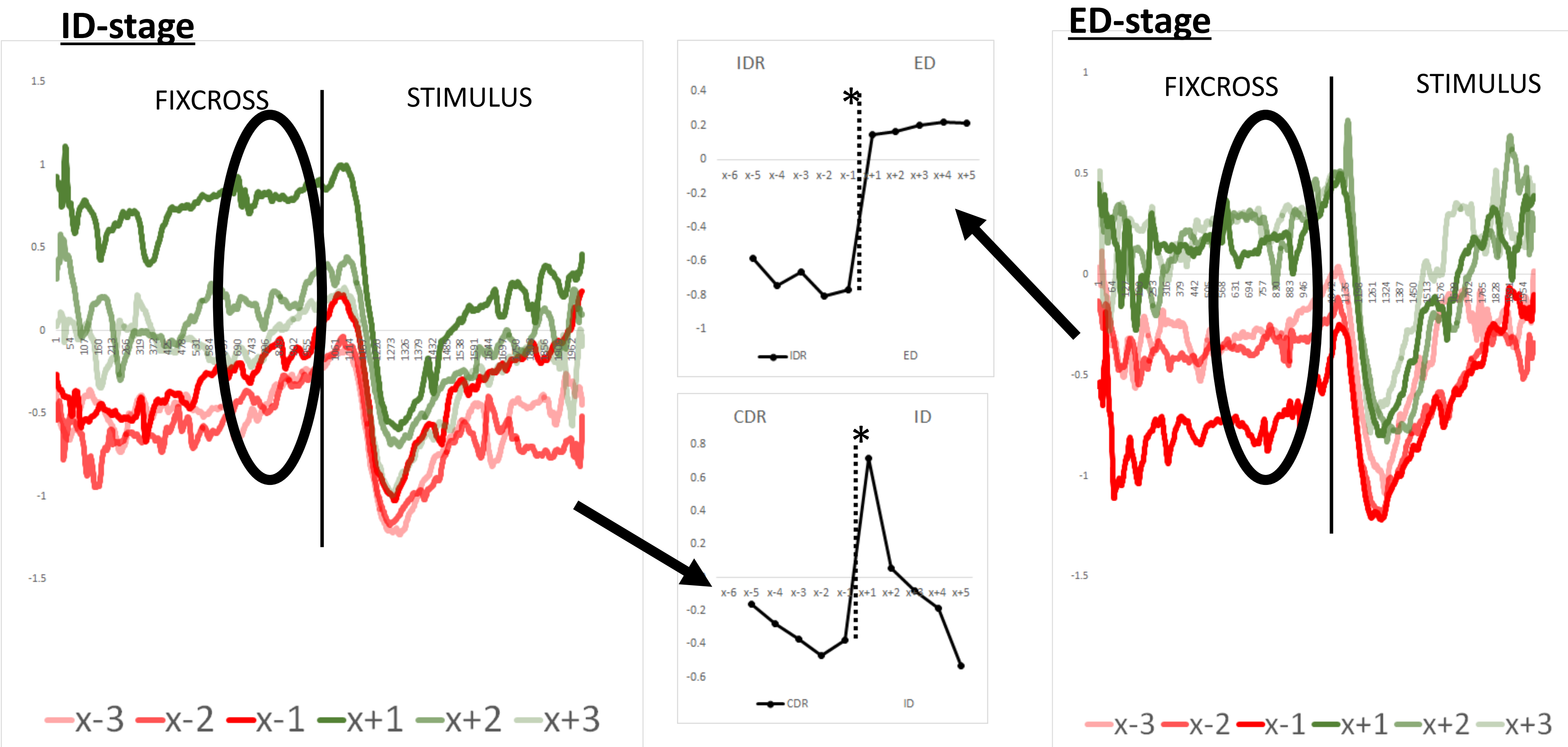


<u>ED-stage</u>



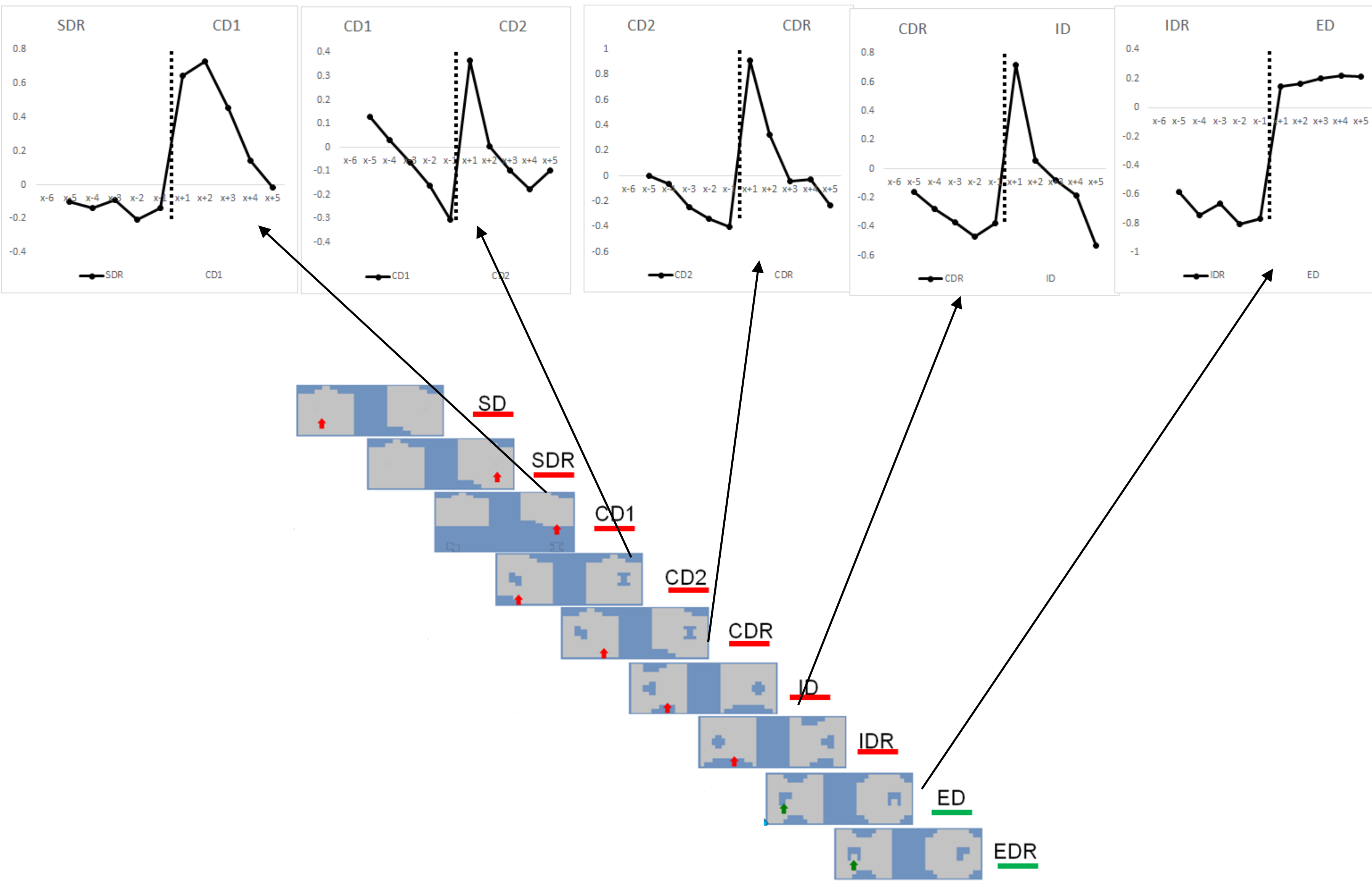
Pupil diameter before and after a switch

Pretrial pupil diameter indexing tonic activity of the LC/NE system BEFORE and AFTER switch

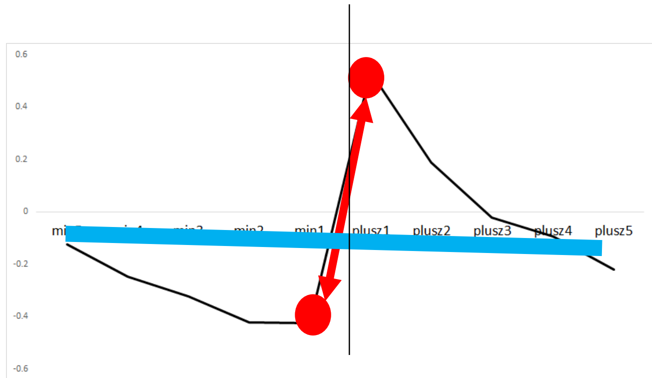


Pupil diameter before and after a switch

The magnitude of the tonic mode of LC-NE response before and after phase shift



Tonic LC activity, behavioral performance and attentional patterns

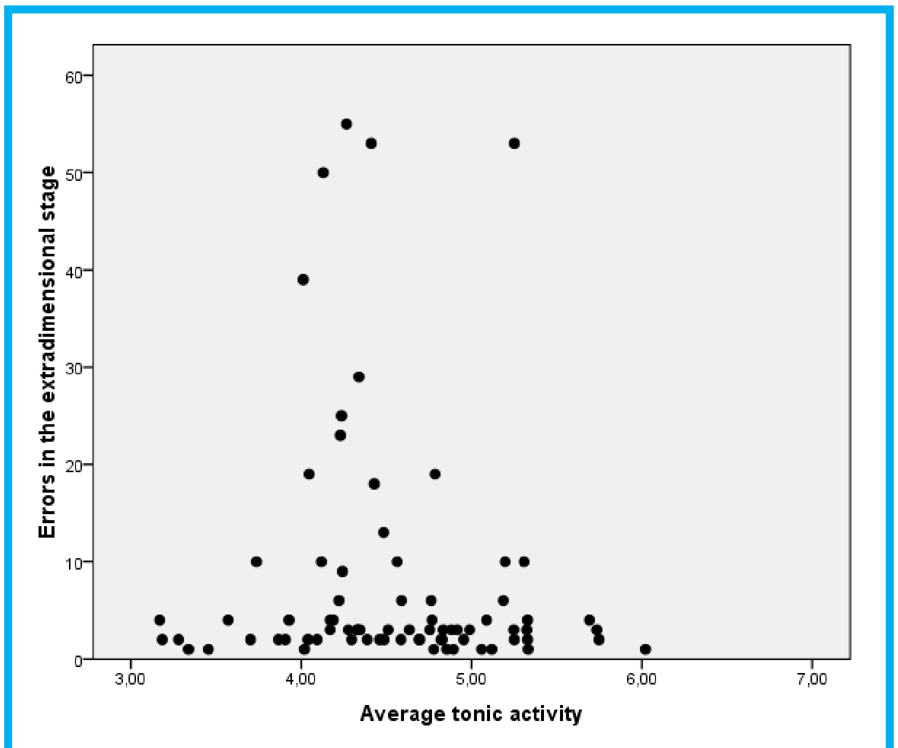


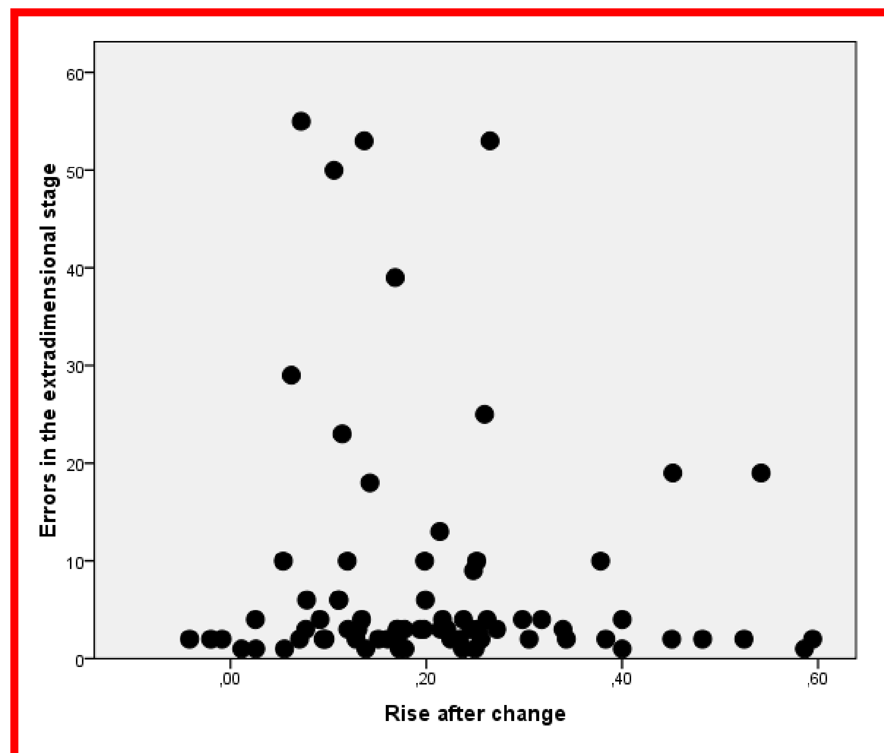
Average pretrial tonic pupil dilation

Increase in tonic activity after changes in reward contingencies

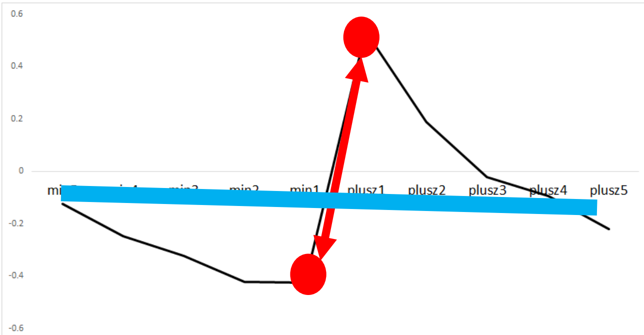
Collapsing data for all stages

Extradimensional set shifting - performance





Tonic LC activity, behavioral performance and attentional patterns

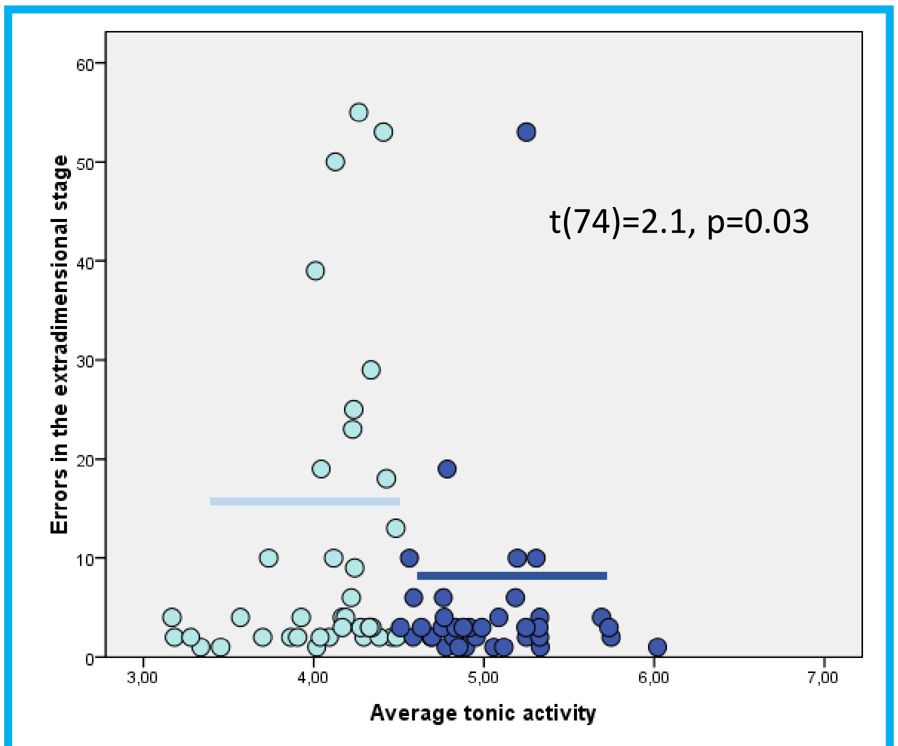


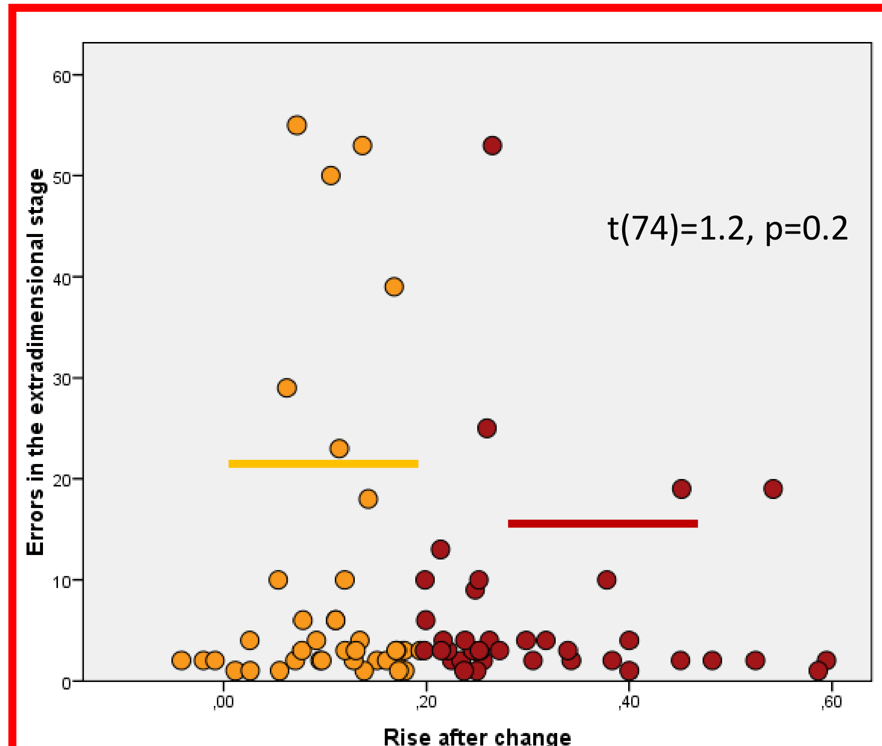
Collapsing data for all stages

Average pretrial tonic pupil dilation → **HIGH** / **LOW**

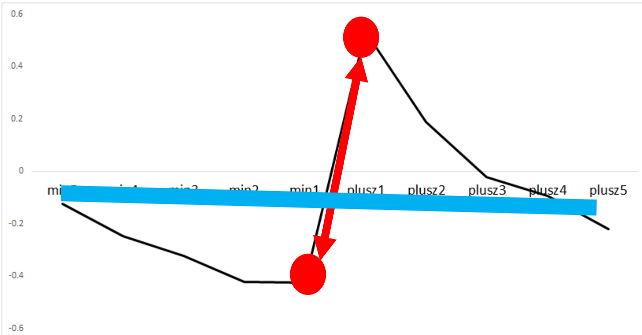
Increase in tonic activity after changes in reward contingencies → **HIGH** / **LOW**

Extradimensional set shifting - performance





Tonic LC activity, behavioral performance and attentional patterns

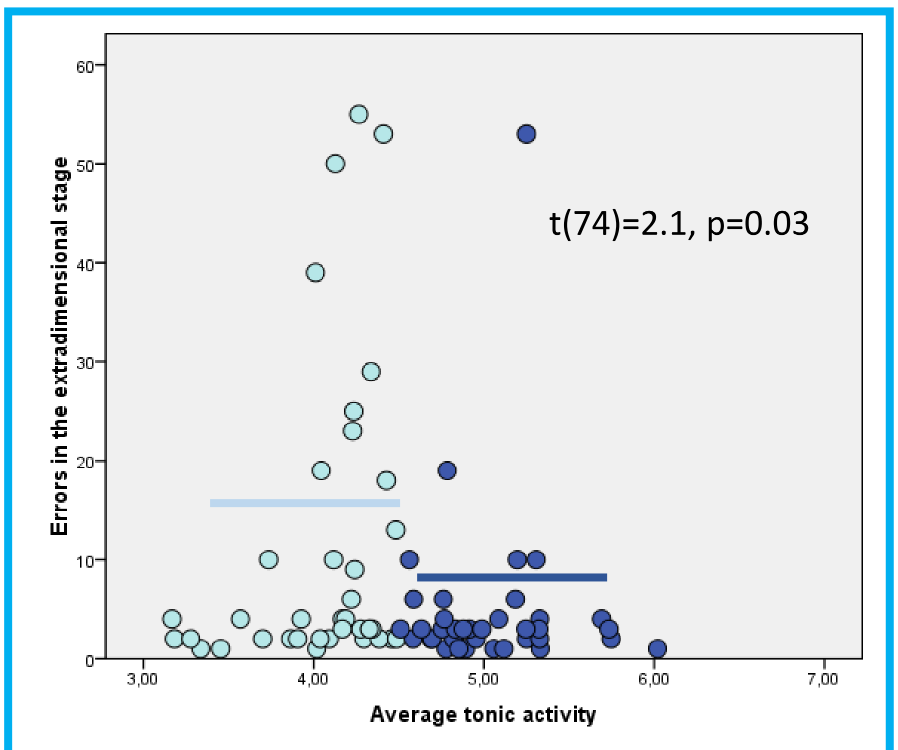


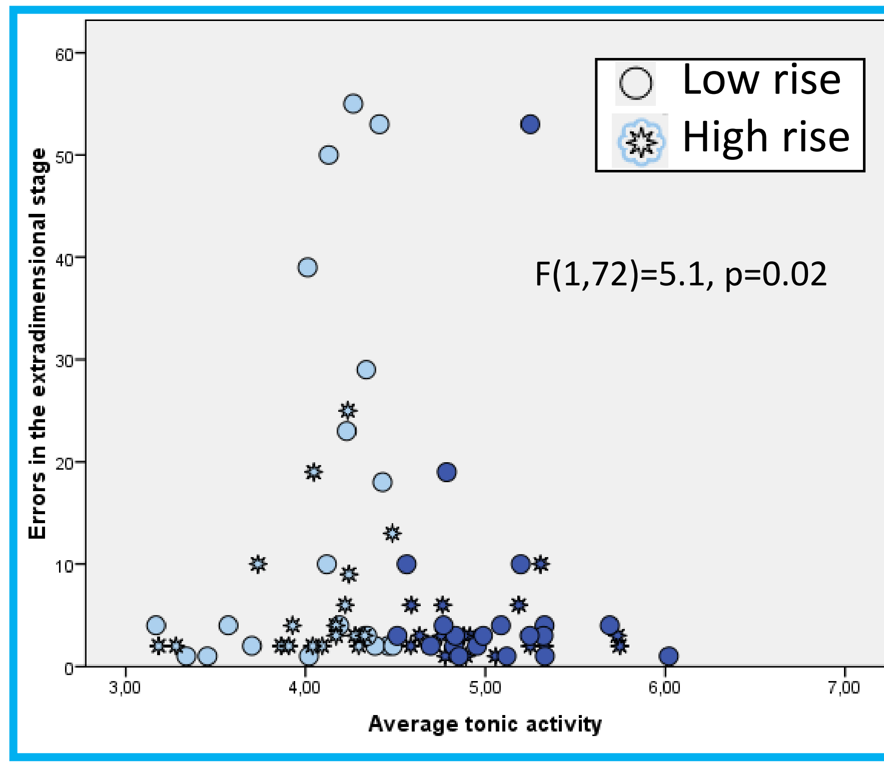
Collapsing data for all stages

Average pretrial tonic pupil dilation → HIGH / LOW

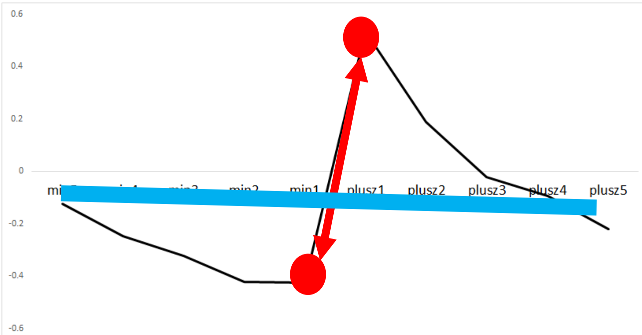
Increase in tonic activity after changes in reward contingencies → HIGH / LOW

Extradimensional set shifting - performance





Tonic LC activity, behavioral performance and attentional patterns

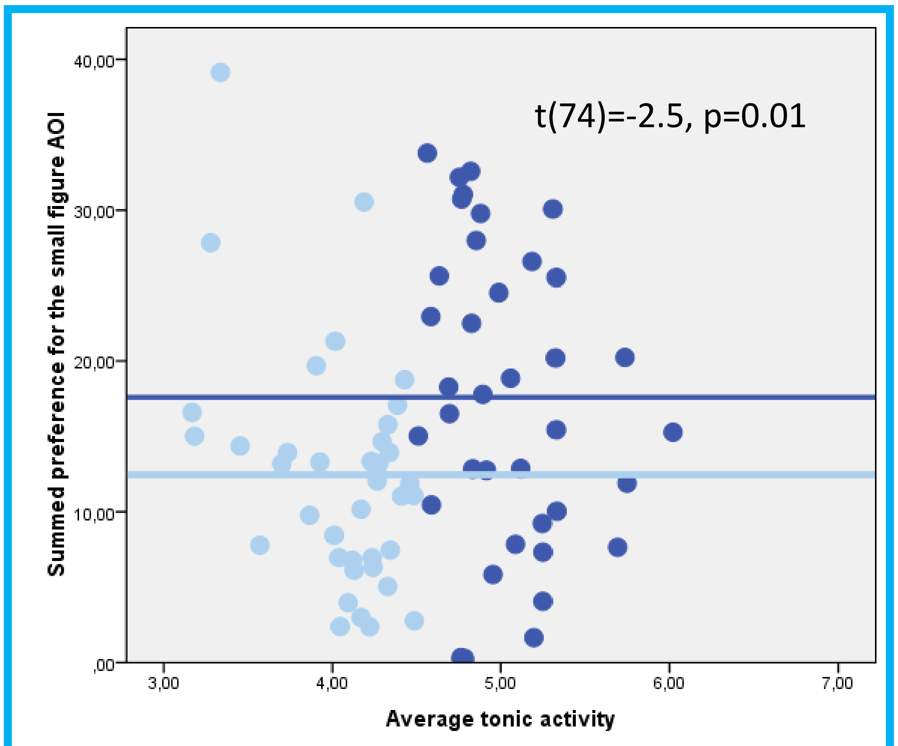


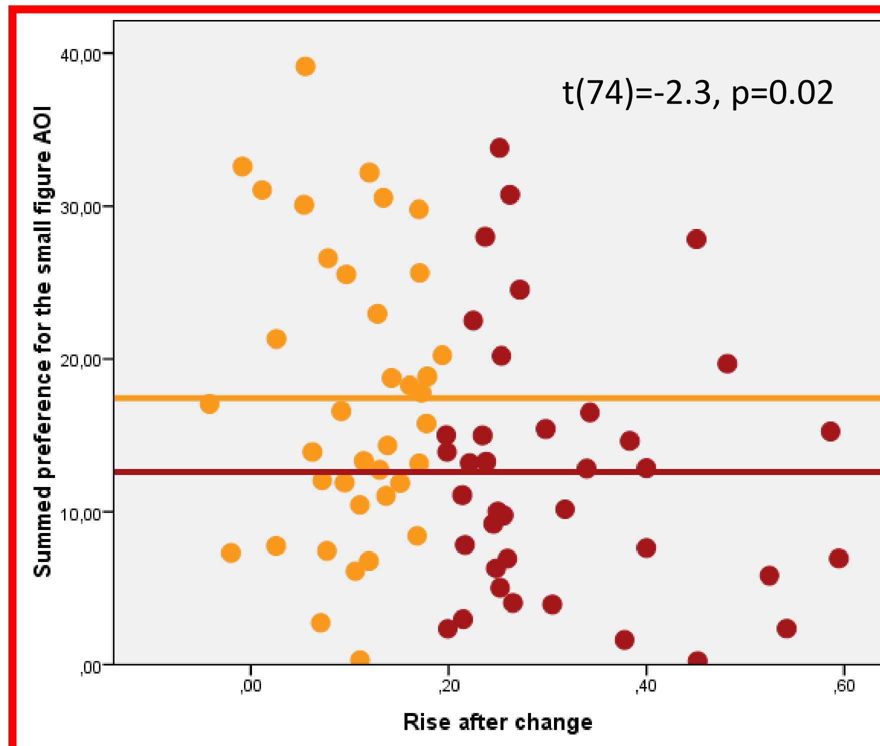
Collapsing data for all stages

Average pretrial tonic pupil dilation → **HIGH** / **LOW**

Increase in tonic activity after changes in reward contingencies → **HIGH** / **LOW**

Dwell time on the irrelevant dimension before ED-stage





Conclusions

Attentional patternis before the extradimensional shift stage predict succesfull attentional set shifting.

Changes in reward contingencies are associated with an increase in tonic activity of the LC (as measured by pupil dilation)

The average tonic activity of LC

The responsiveness of the LC to new reward contingencies

predicts

attentional set shifting performance

Attentional patterns for task-irrelevant information before the ED stage

FUTURE STUDIES:

→exploration/exploitation in different paradigms (e.g. memory retrieval, verbal fluency, economic decision making)

→The interaction of dopamine and noradrenaline in determining the exploration-exploitation tradeoff

→Pathological populations (e.g. Parkinson’s disease)

→Personality trait correlates