

# Reaction time methods

Prof. Torsten Schubert

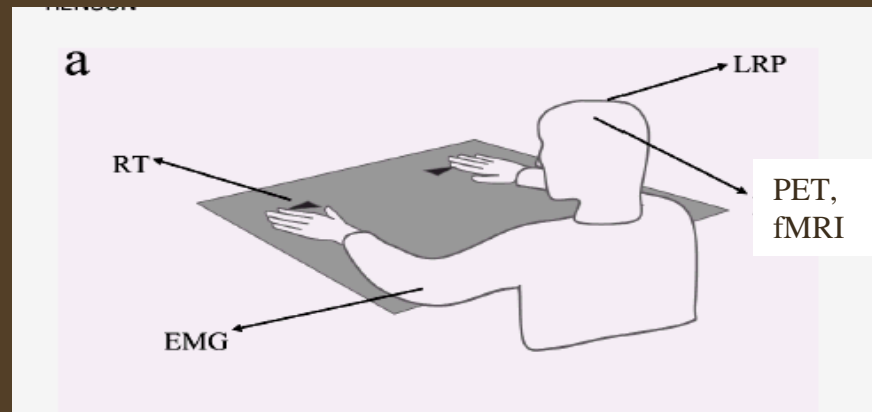
Behavioral data as a  
methodological basis in cognitive  
neuroscience

- Plan:
- 1. Introduction
- 2. Mental chronometry
  - Basic questions
  - Subtraction method
  - AFM
  - Contemporary alternative models
- 3. Mental chronometry in complex situations

# 1. Introduction

Behavioral data (RTs, error data):

- Not the only one measure when investigating/analysing mental events
- „one“ indicator for mental events (among others)



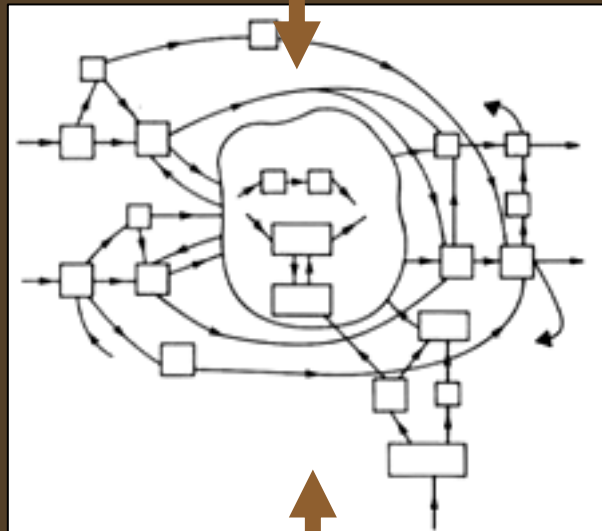
## Data and methods

Introspection

Objektive  
measurement  
and manipulation  
of behavior (RT,  
errors, threshold  
measures, etc.)

Objektive  
measurement of  
neural activity

Subjektive  
experience



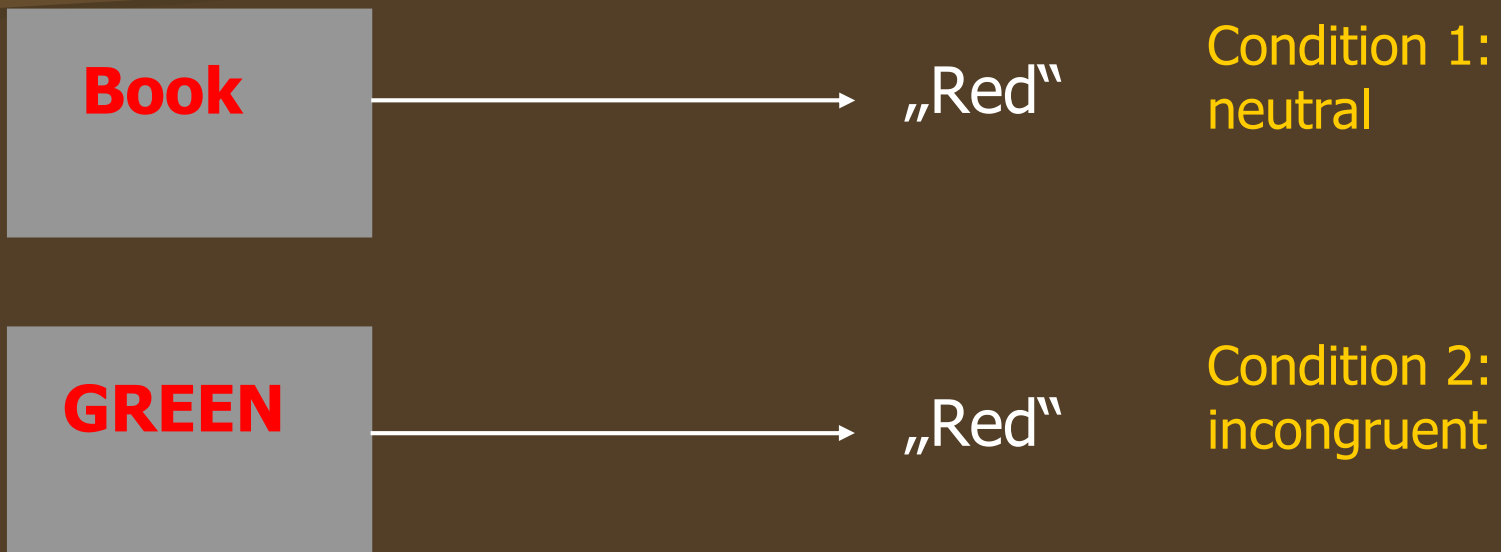
## Level of analysis

Experience, events,  
attitudes

**COMPUTATIONAL  
or functional**  
(Representations,  
processes, modules,  
architecture)

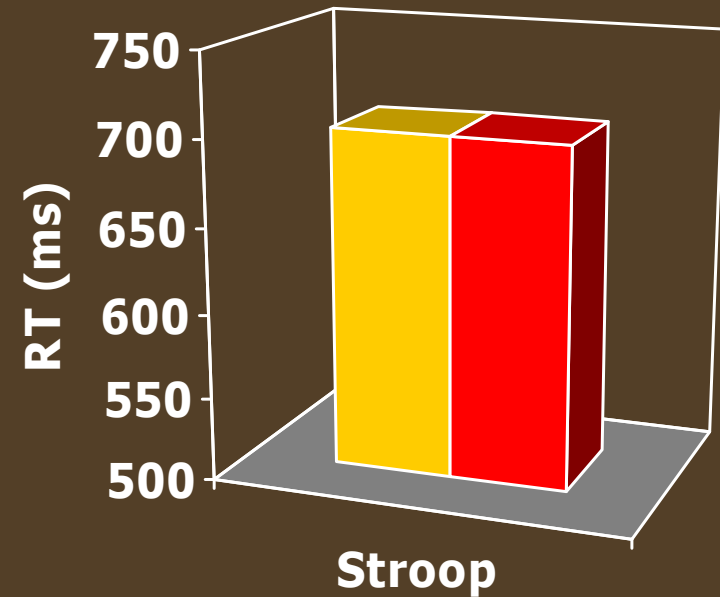
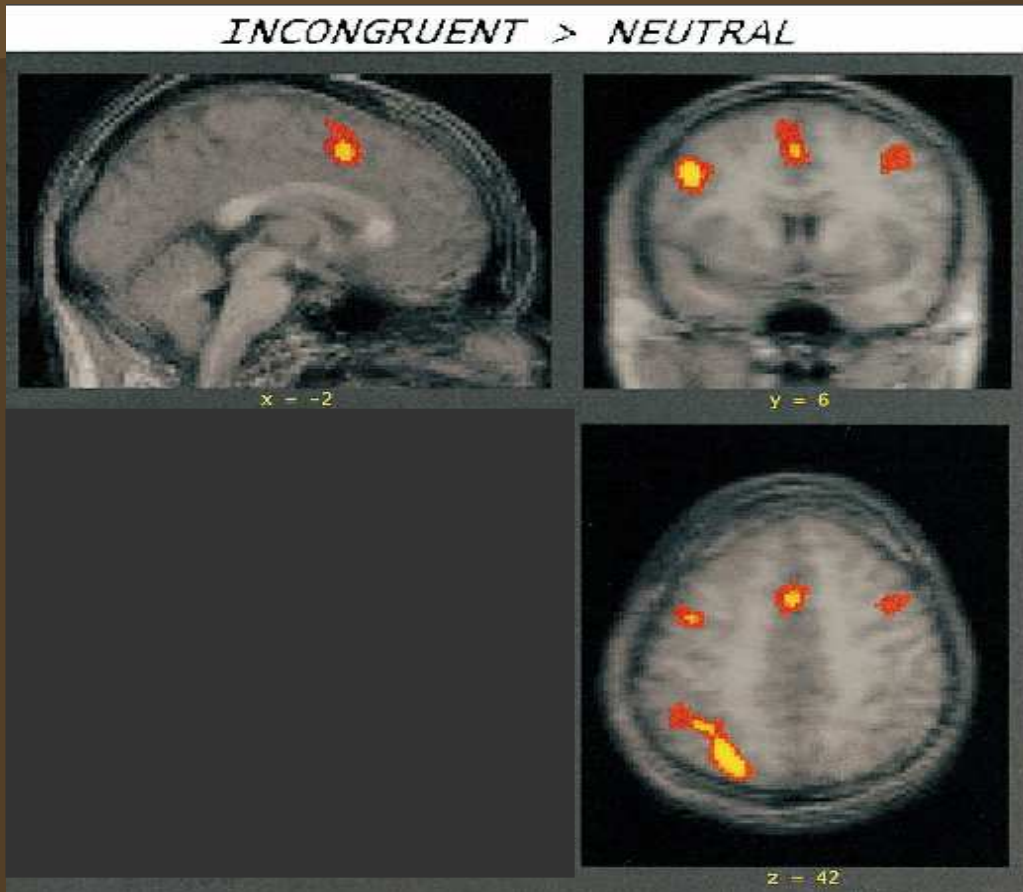
**NEURONAL**  
(How realize neurons the  
computations? What is  
the localisation &  
networks)

# Example: Stroop



Milham (2001)

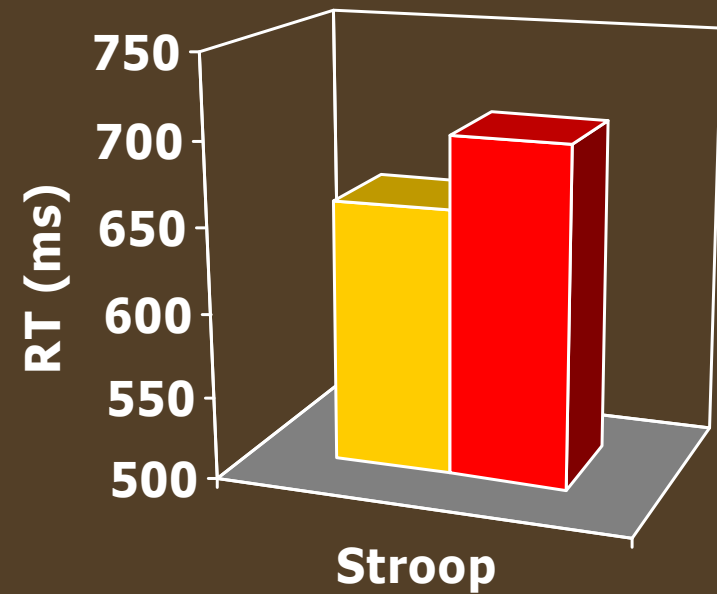
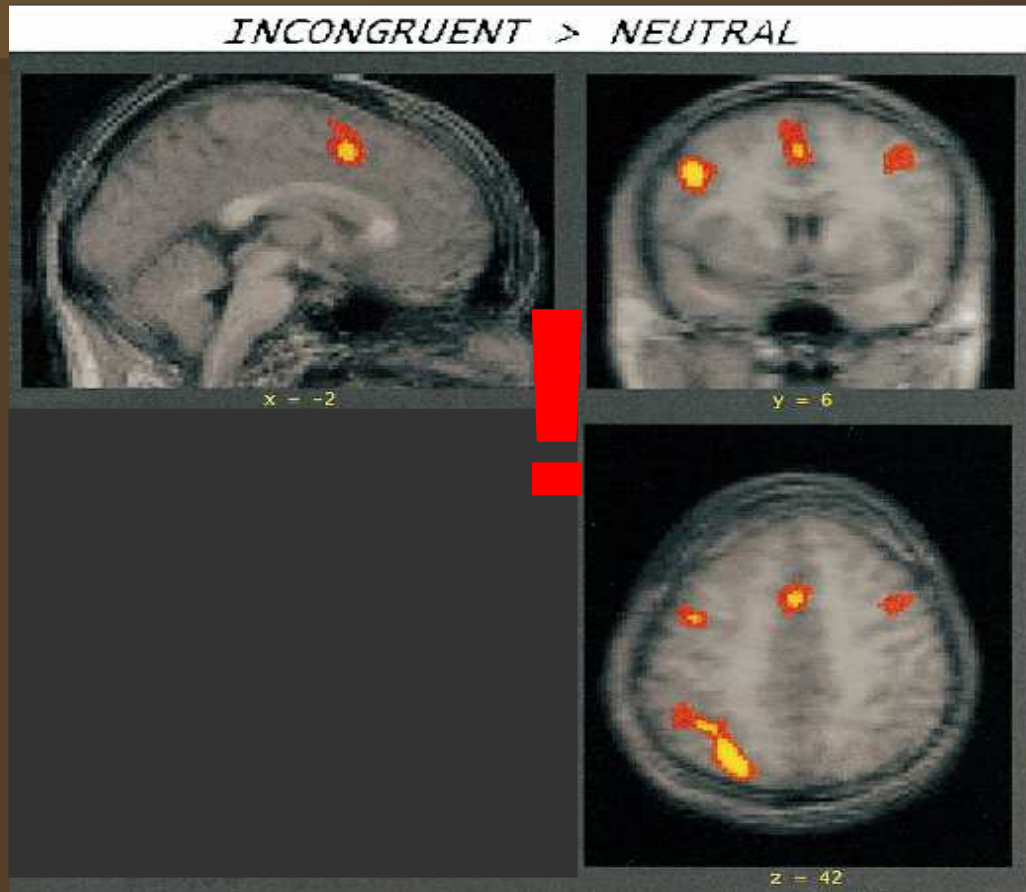
# Mental events $\Leftrightarrow$ measurable events in the brain



■ neutral  
■ incongruent

Milham (2001)

# Mental events $\Leftrightarrow$ measurable events in the brain



■ neutral  
■ incongruent

Milham (2001)

## 2. Mental Chronometry

For the interpretation of data we need a theory – about what indicate reaction times and error data:

### MENTAL CHRONOMETRY

Goal of mental chronometry is to identify and to uncover mental processes, which can not be overtly observed. The way for this is the manipulation of the tasks and/or of variables determining the behavior of participants in the tasks.

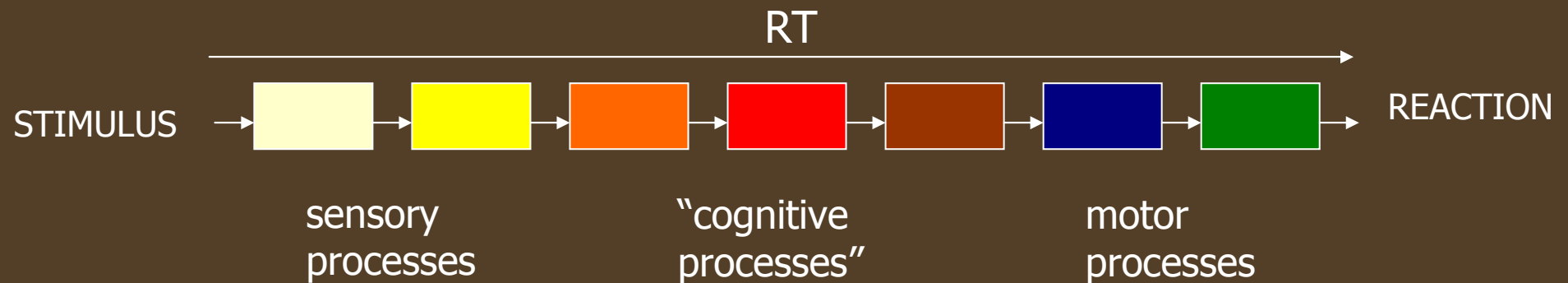


Measurement of (manual, verbal, eye movement)

- reaction times
- Error rates
- speed-accuracy trade-offs

# Questions of mental chronometry

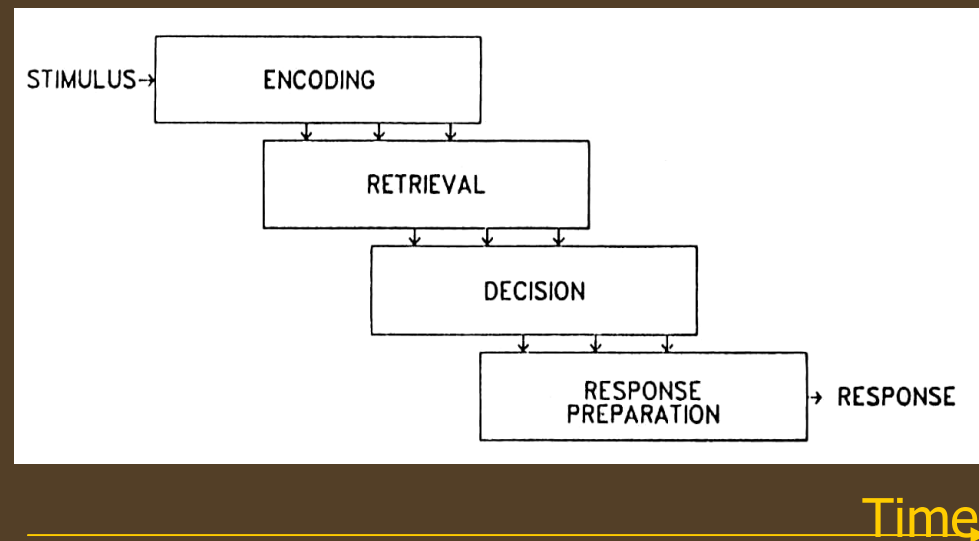
- Which components of mental processes are located between stimulus and reaction and can be distinguished on the basis of separable processing times?



- How many subcomponents?
- How long is their duration?

- How do the processing components interact with each other?
- How is the information transmission between and within the processing components?

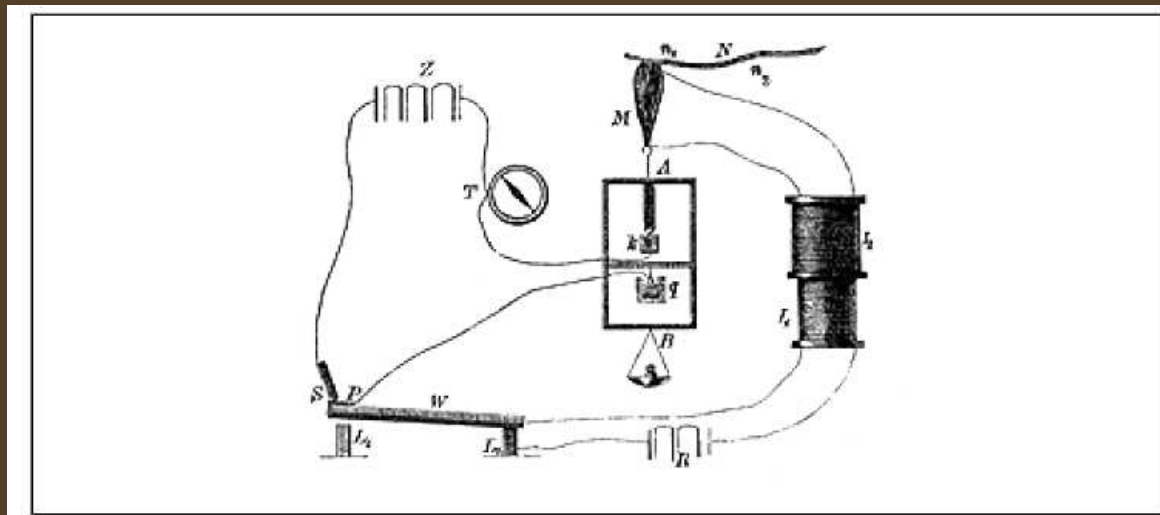
P **RS** MR



- Continuous versus discrete?
- Are processing components organized in serial or parallel or partially parallel (cascade) form?

# History

- before 1850 – philosophical discussion about cognition and action; measurement of mental processes appeared not possible
- 1850 Helmholtz: Introduction of the „Simple Reaction Time Procedure“- neural transmission time  $\sim 30\text{m/s}$   
= basis of mental chronometry



# History

- before 1850 – philosophical discussion about cognition and action; measurement of mental processes appeared not possible
- 1850 Helmholtz: Introduction of the „Simple Reaction Time Procedure“- neural transmission time  $\sim$  30m/s (frog)  $\rightarrow$  60 ms human
  - = basis of mental chronometry
- 1850-1900 „Golden Age“, 2 main issues
  - reaction times (Donders, Wundt)
  - error rates, Speed-Accuracy Tradeoffs (Woodworth, Hick)

# Donders' subtraction idea

## ■ Donders (1868)

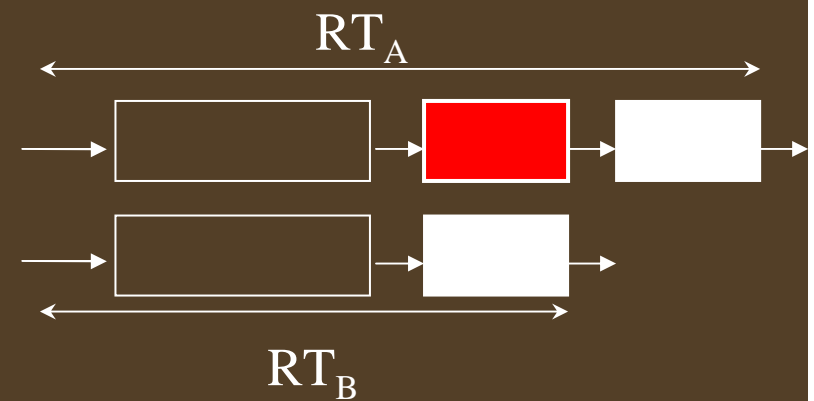
*The idea occurred to me to interpose into the process of the physiological time some new components of mental action. If I investigated how much this would lengthen the physiological time, this would, I judged, reveal the time required for the interposed term.*

*(Donders, 1969, p418)*

### – Assumption of 'pure insertion':

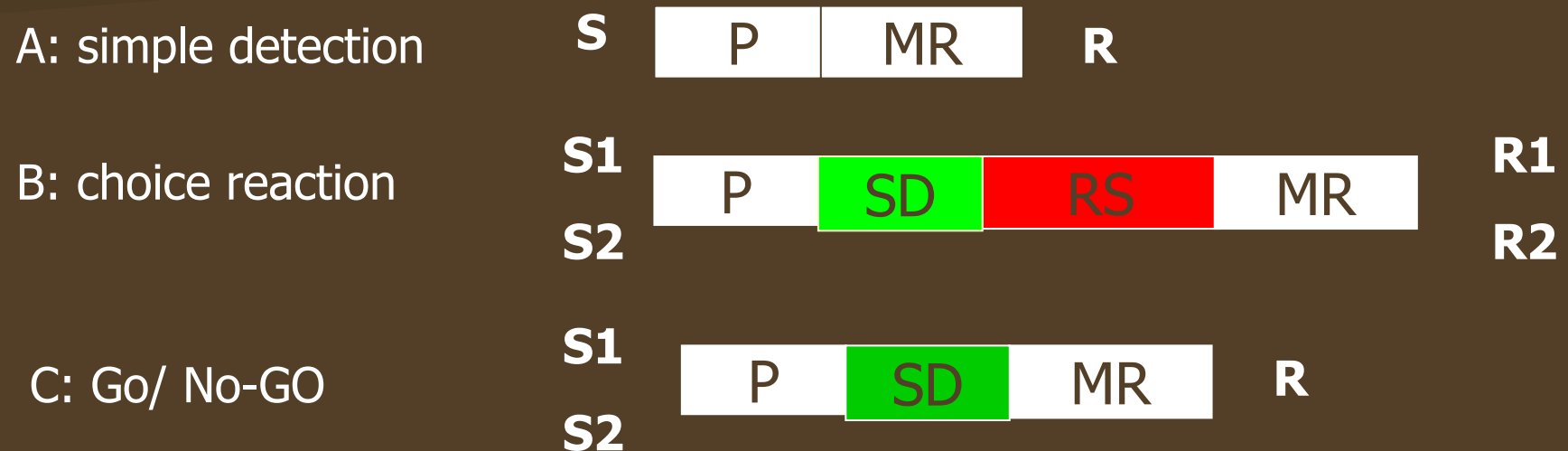
- Task A has all the stages of Task B lacks an extra process, then
- Extra process can be measured by:

$$RT_A - RT_B$$



# Donders (1868) method of subtraction

## Comparison of different tasks



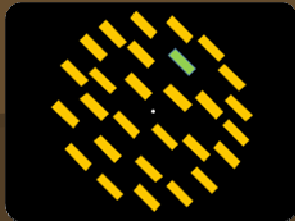
stimulus discrimination & response selection =  $RT(B) - RT(A)$

response selection =  $RT(B) - RT(C)$

stimulus discrimination =  $RT(C) - RT(A)$

# Rangelov Dragan (2010) visual search task

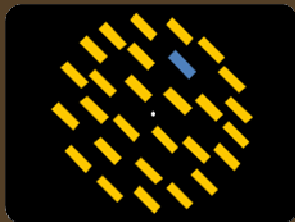
Search detection



Present/absent



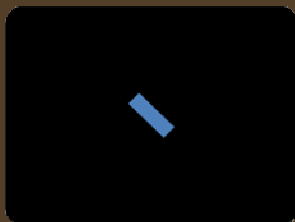
Search discrimination



Right/left



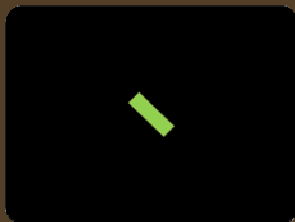
Non-search detection



Present/absent



Non-search discrimination



Blue/green

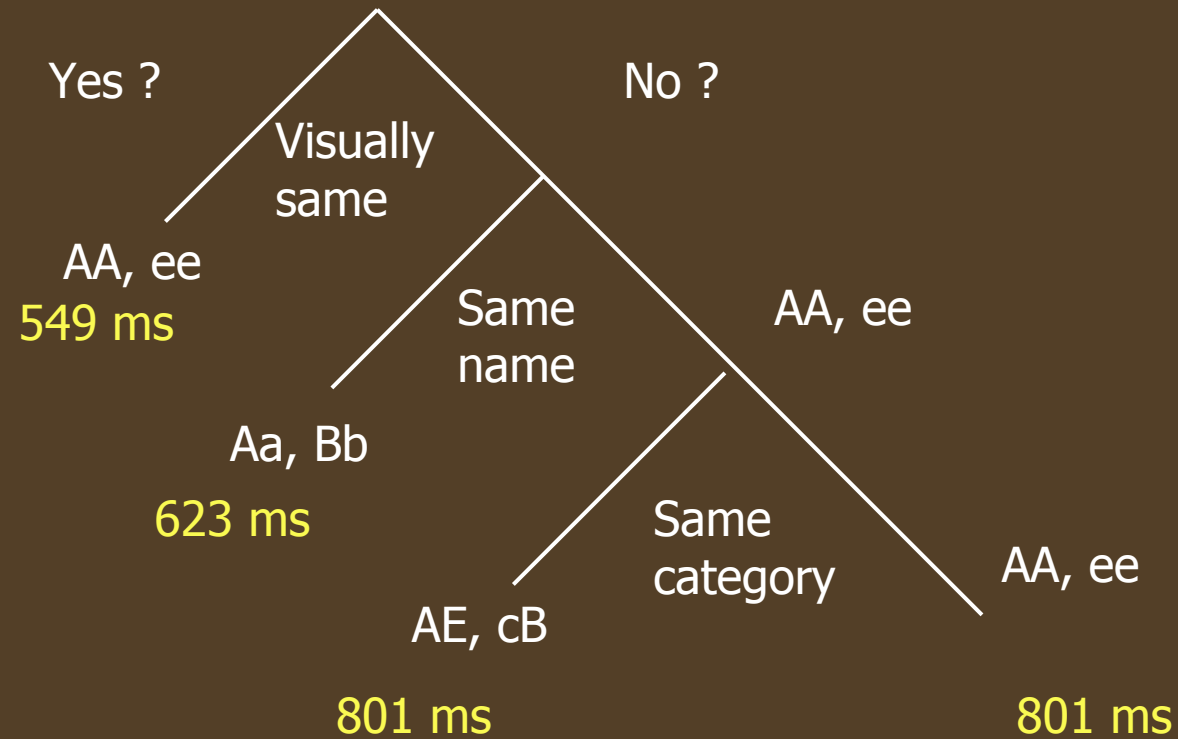


## Same – different task Posner & Mitchell (1967)

- Task: Are two visually presented letters members of the same category (vowel/consonant) or not?
  - AA same      - AK different
  - Aa same      - Ak different
  - AE same      - AB different

Assumption: First testing of visual identity → testing of name identity → testing of categorical identity

# Same – different task Posner & Mitchell (1967)



Name comparison: 74 ms (623 – 549 ms)

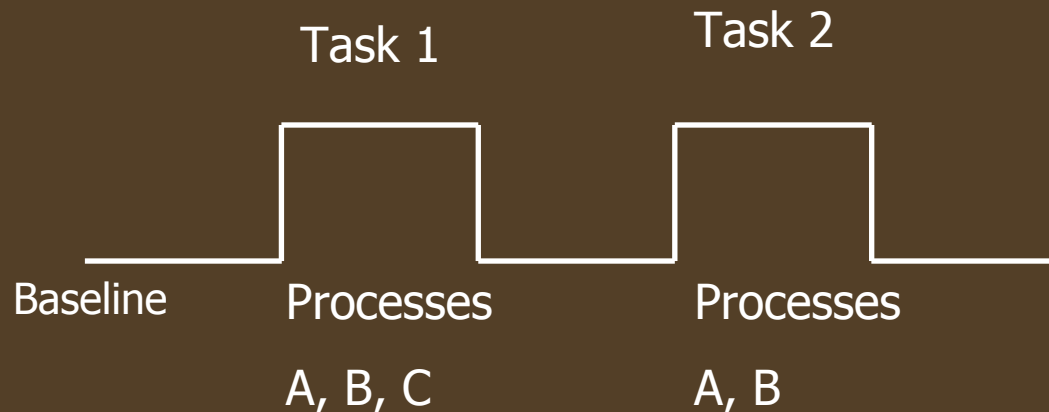
Category comparison: 178 ms (801 – 623 ms)

# Problems with the method of subtraction

- PURE INSERTION:
- insertion/removal of processing stages does not influence other processing stages (i.e. their duration or their dynamics)
- Külpe (1893) – criticism; insertion of a new process → changes of the whole task (later “Gestalt”)
- Subcomponents are successive processing stages:
  - Subcomponents do not overlap and add independently to the overall RT
  - Does C task (no-go) really not involve a response selection stage (deciding whether to respond or not)? → Wundt D - reaction; simple reaction but wait for complete SD
- nevertheless excessive application; e.g. Wundt and today

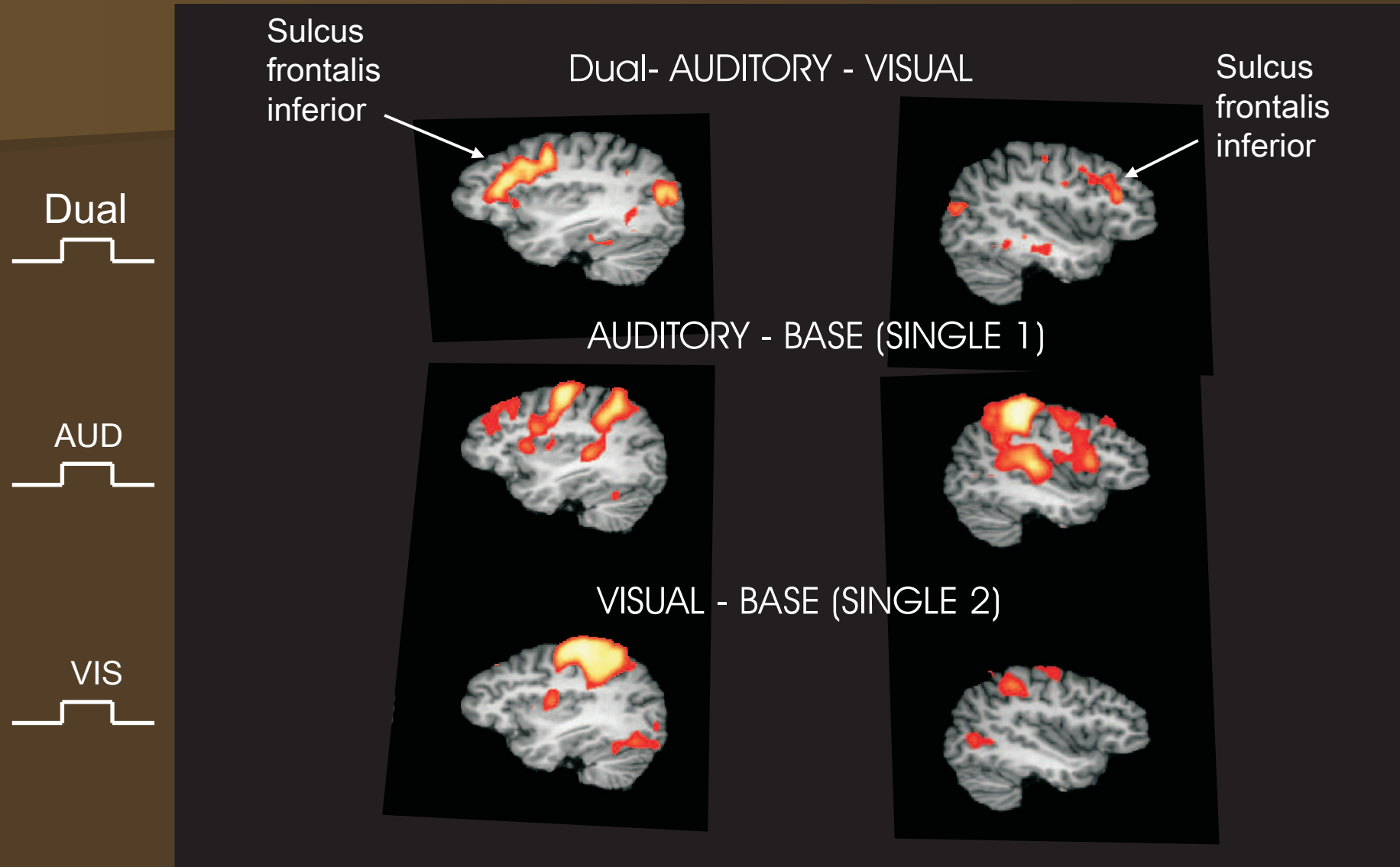
# Use of subtraction method in functional imaging:

Prevailing method in fMRI (PET): cognitive subtraction to find regions associated with certain cognitive functions



fMRI activation (Task 1) – fMRI activation (Task 2) → brain area(s) related to C

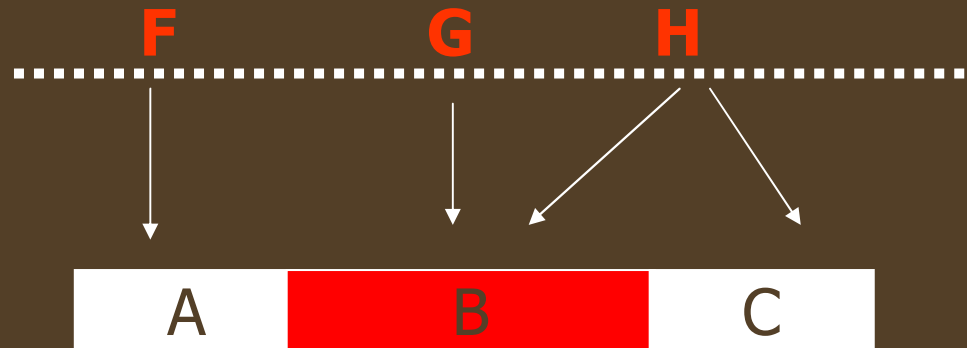
# Subtraction method in Cognitive Neuroscience





## Sternberg's Additive Factor Method (1969) AFM

Which processing stages exist as independent processing stages?



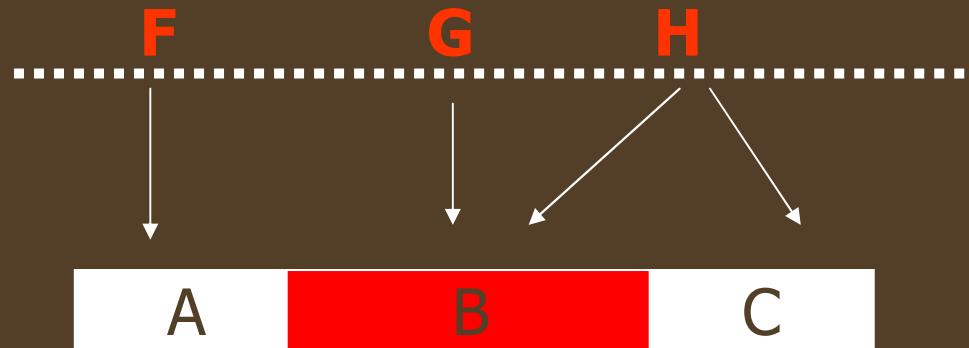
Main idea:

- conduct experiments
- apply several experimental manipulations, which change the duration of presumed processing stages
- analyse the effects of these manipulations on the overall reaction time

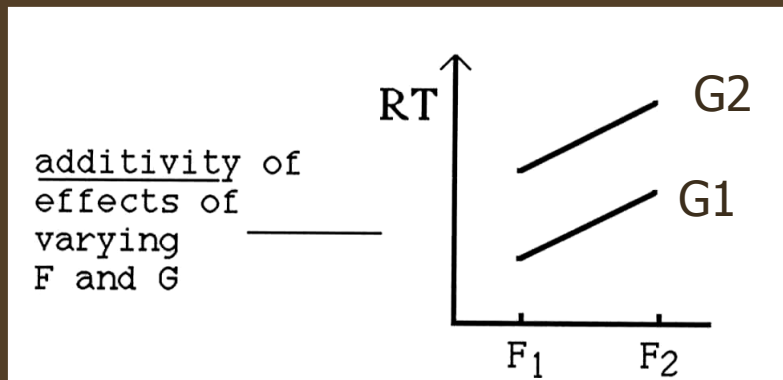


# Sternberg's Additive Factor Method (1969) AFM

Which processing stages exist as independent processing stages?



Main idea: If two factors affect two independent stages, then their effects on the overall RTs should be additive ones.

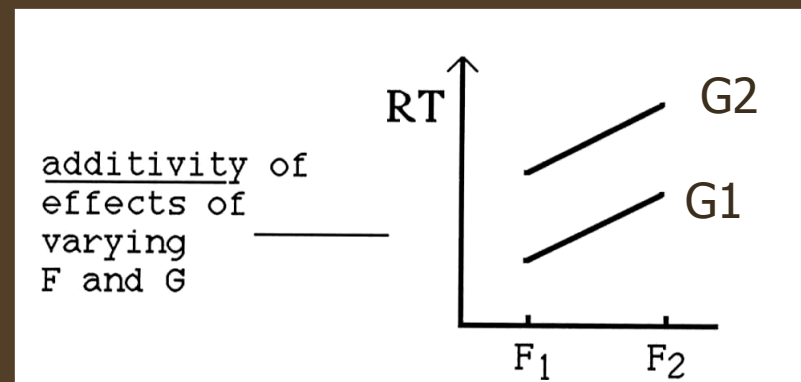
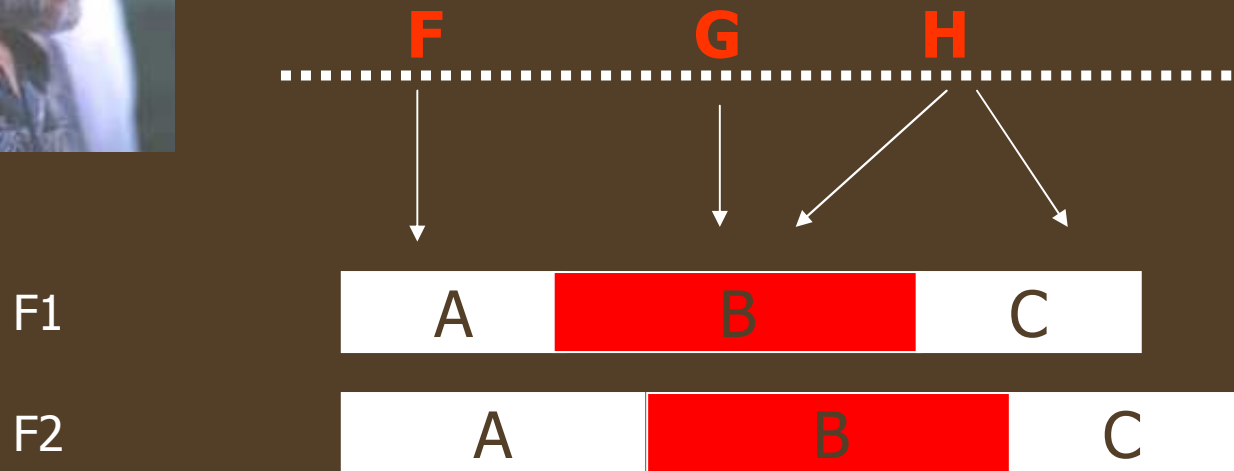


$$RT(F2/G2) - RT(F1/G2) = RT(F2/G1) - RT(F1/G1)$$



# Sternberg's Additive Factor Method (1969) AFM

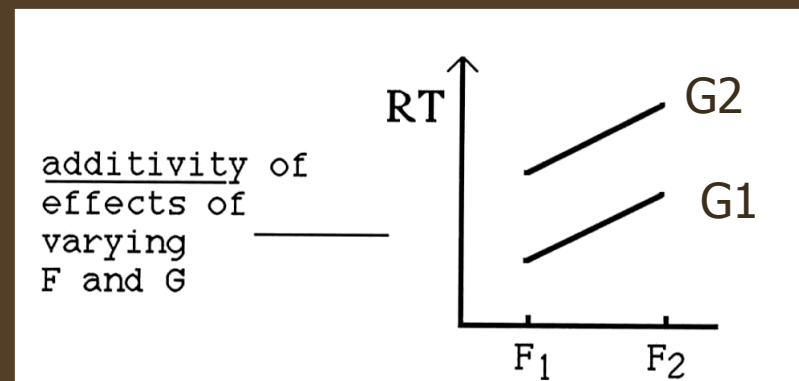
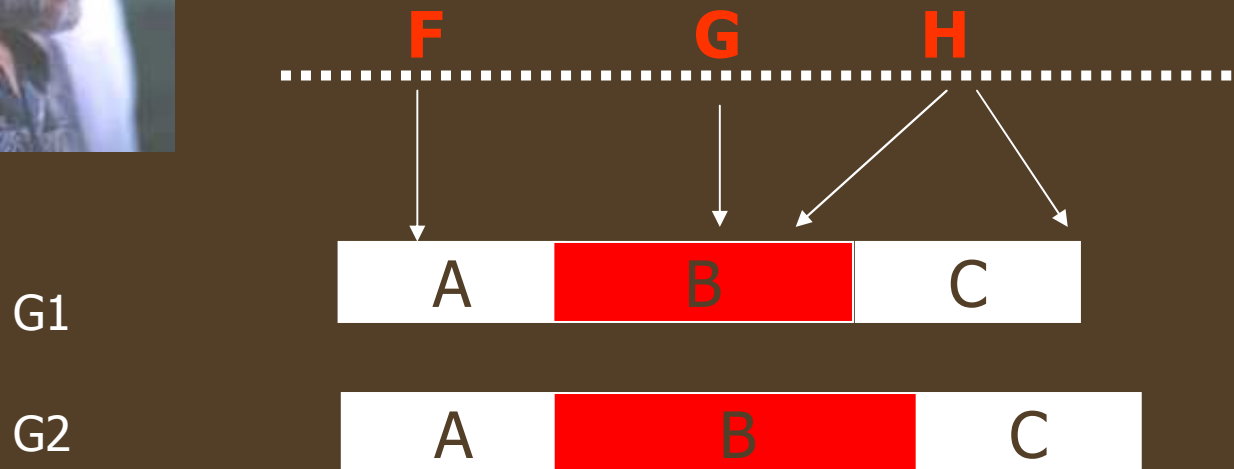
Which processing stages exist? Which factors affect which stages?

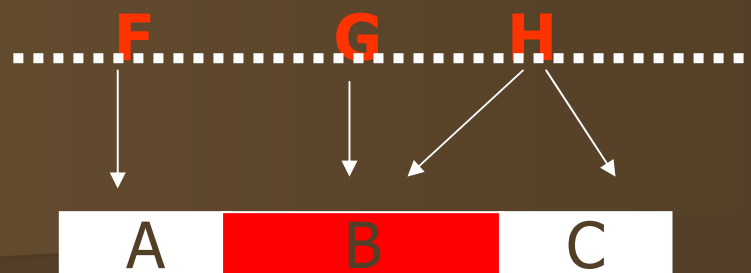




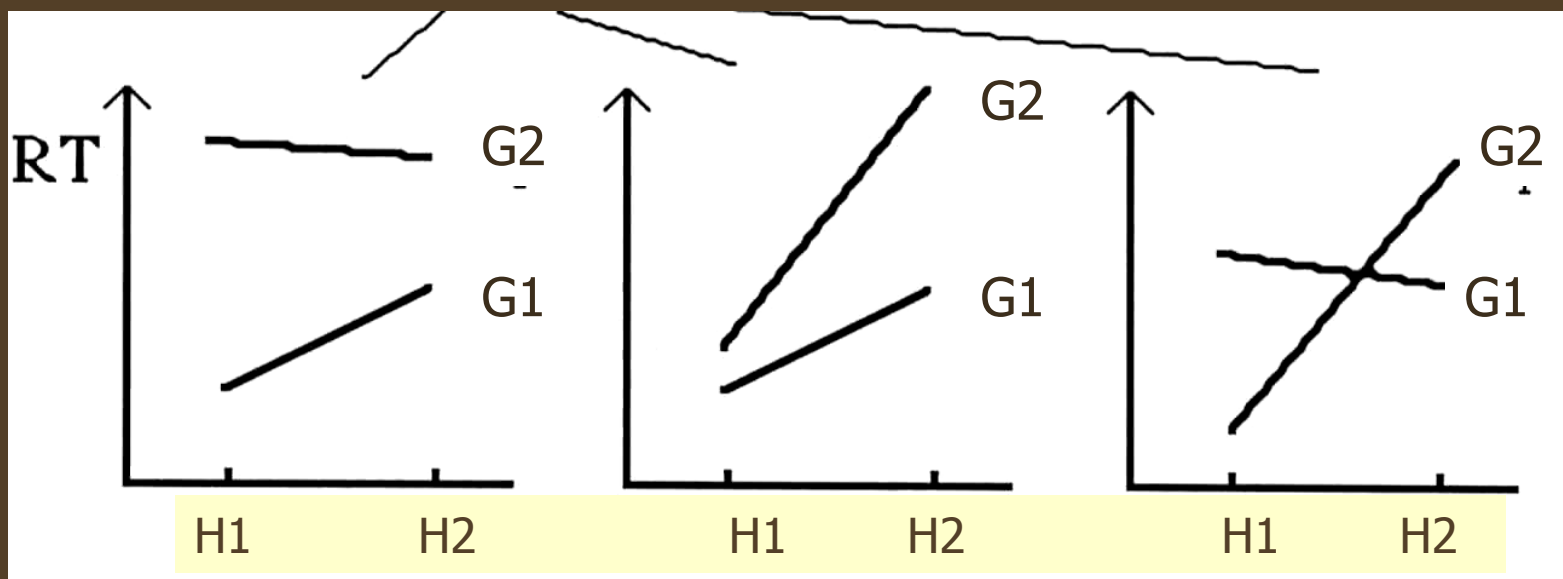
# Sternberg's Additive Factor Method (1969) AFM

Which processing stages exist? Which factors affect which stages?





If two factors show an interaction effect on the RT, then they affect at least one common processing stage.



# Results of many studies that used AFM logics (from: Sanders, 1980, A stage analysis of Reaction Processes. Acta Psychologica)

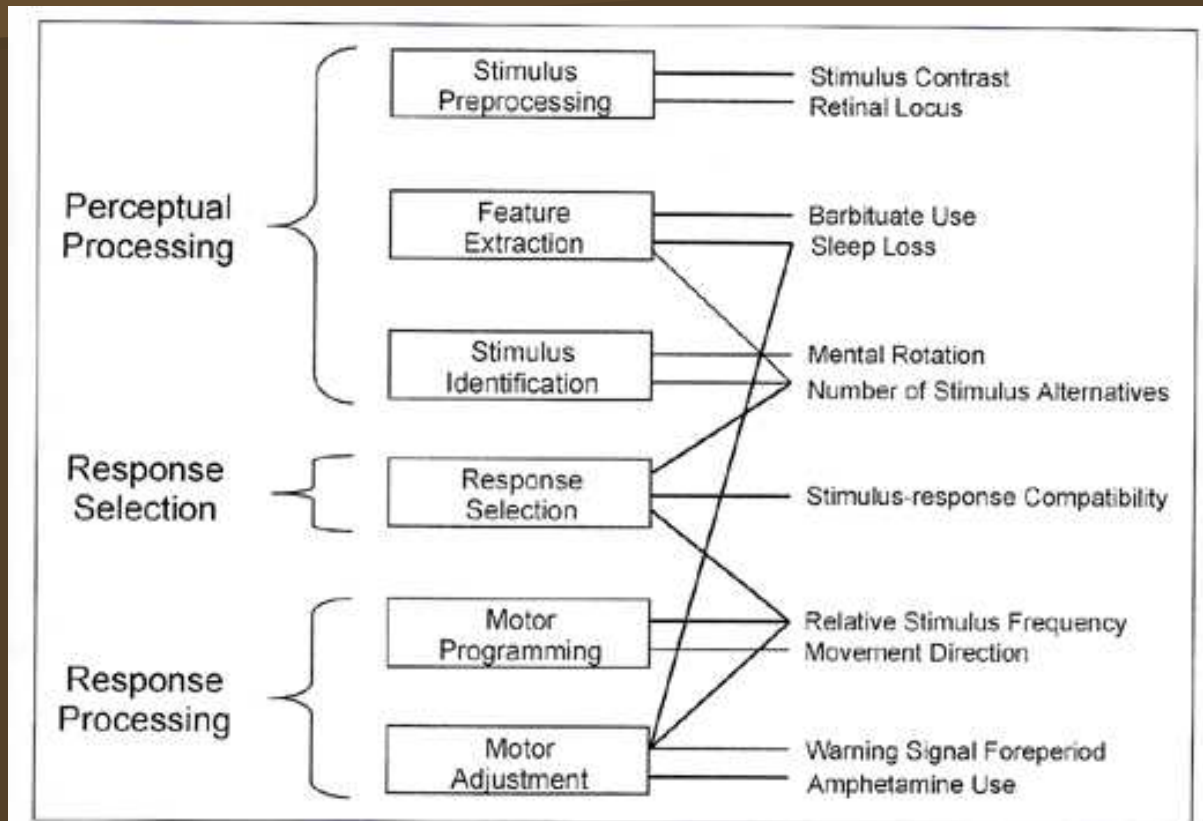
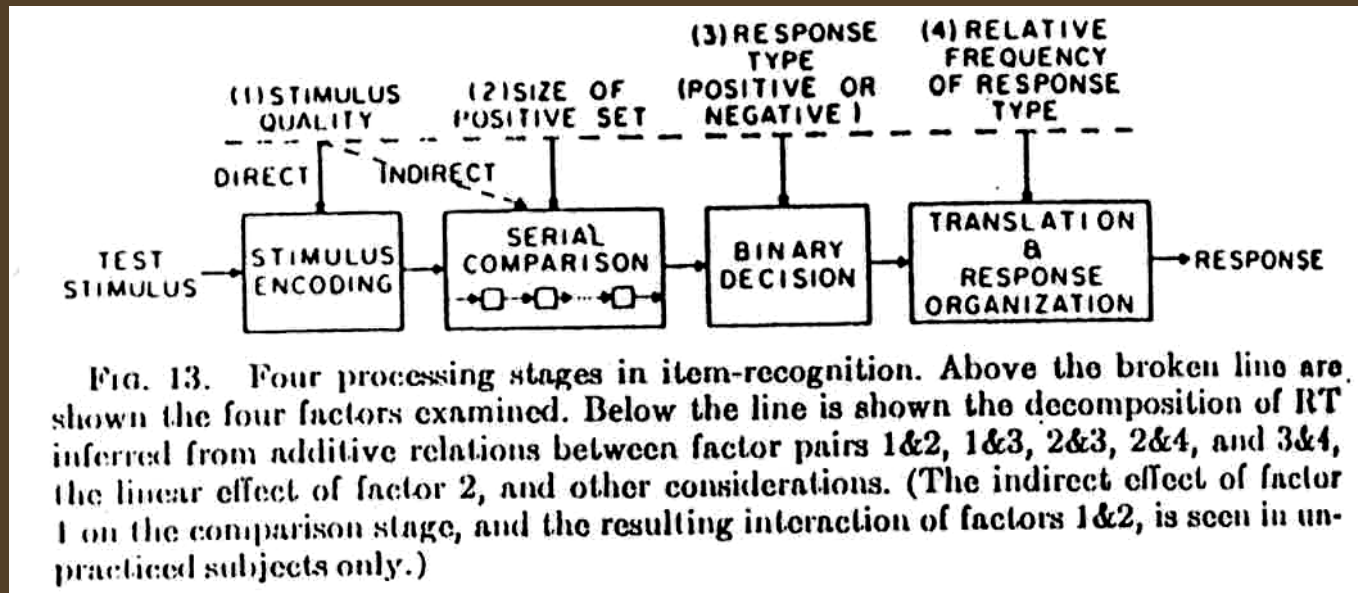


Figure 2.4 Summary of conclusions drawn from additive factors studies of human information processing.

Example:  
 „Sternberg“- task  
 – decision whether a  
 probe item is member  
 of a memory list or not



# An example of AFM in cognitive neuroscience

■ Dehaene S (1996) The organization of brain activations in number comparison: Event-related potentials and the additive-factors method. *J Cogn Neurosci* 1: 47–68.

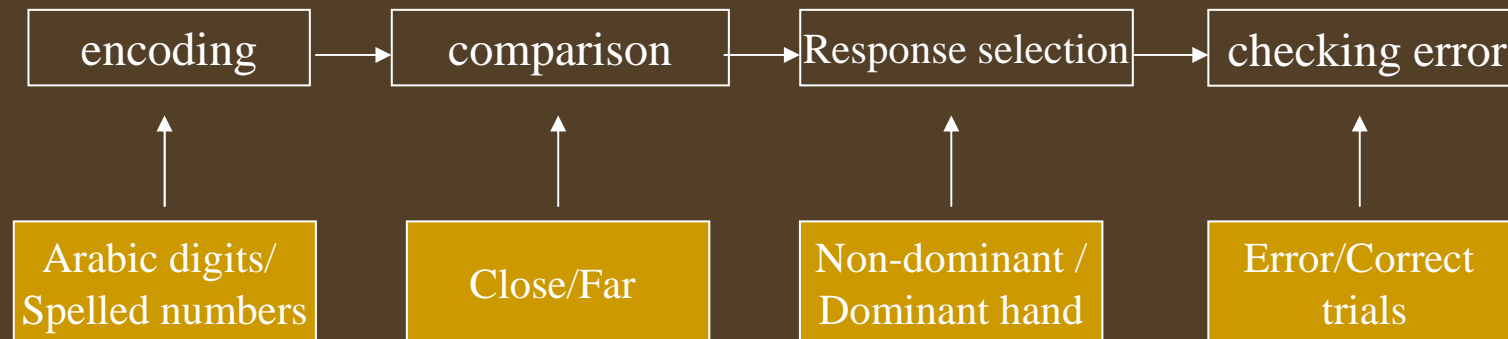
– investigated cognitive and neural mechanisms of number comparison: a number is presented on the display and subjects have to decide whether the number is less than or greater than five.

– Manipulations:

- Input: Arabic digits / spelled numbers (4 / four)
- Comparison: Near 5 / far from 5
- Response: dominant / non-dominant hand

# An example of AFM

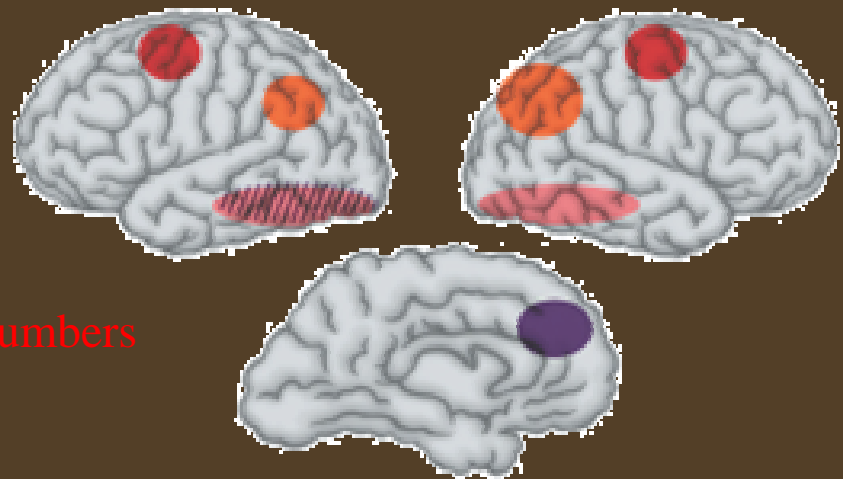
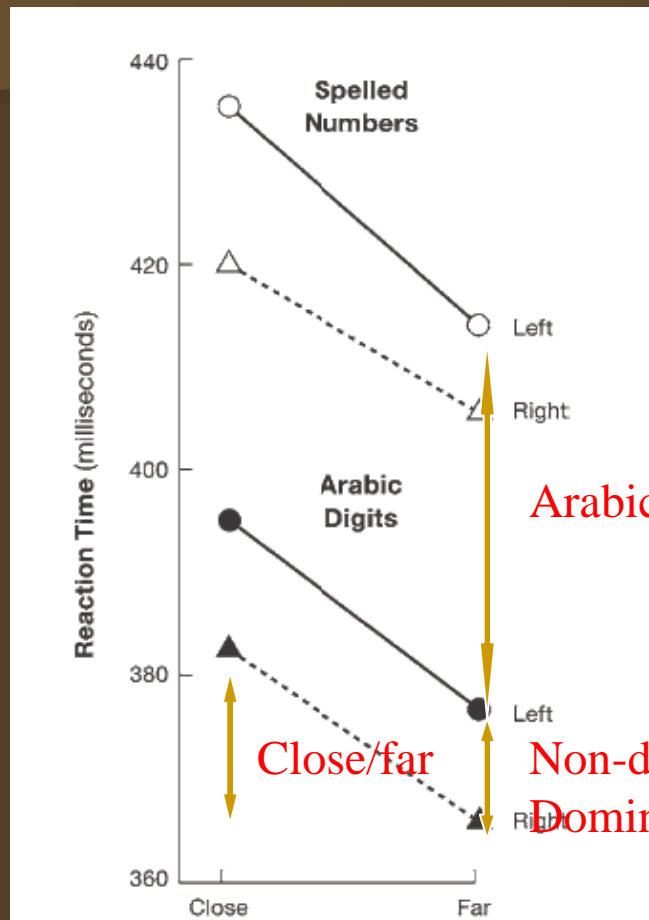
–The authors proposed four different stages



–According to additive factors theory, a variable that affects overall reaction time by varying the time to complete one stage will be additive with the effects of factors that affect other stages.

# An example of AFM

EEG and fMRI studies showed these four factors processed in different regions



- arabic digits
- arabic digits/spelled numbers
- comparison
- movement
- error correction

## Advantages:

- No problem with „pure insertion“ – manipulation of the duration of a processing stages
- comparison between one and the same type of tasks → criticism of Külpe does not hold

## ■ Problems:

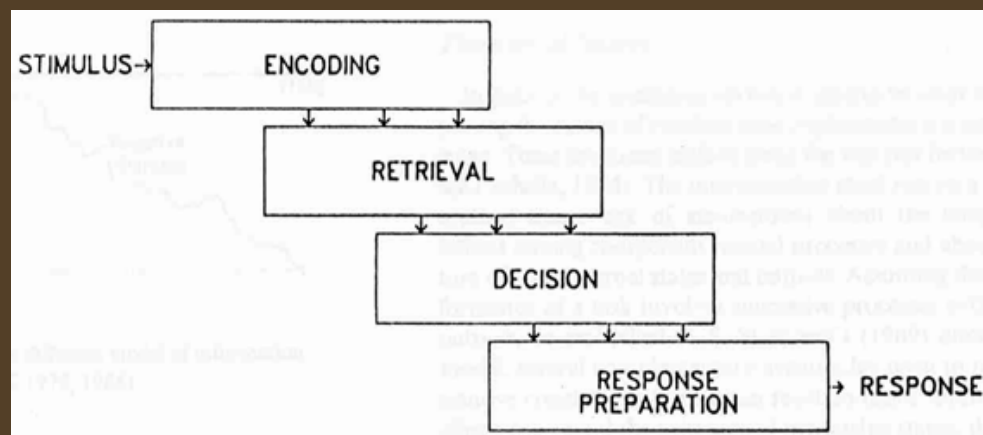
- Basic assumption: factors can affect certain processing stages (while leave other stages unaffected)
- stages should not temporally overlap („seriality“ assumption)
- output of a stage is a discrete information „quantum“, all-or-non-principle
- interpretation of non-additive (interaction) effects?
- problems with the reversed inference:
  - additive effects of two factors does not necessarily mean that two separate stages
    - If p then q; If q then p?

Nevertheless: AFM is one of the most successful analytical tools in modern reaction time psychology.

# Alternative theoretical models: Cascaded processes model

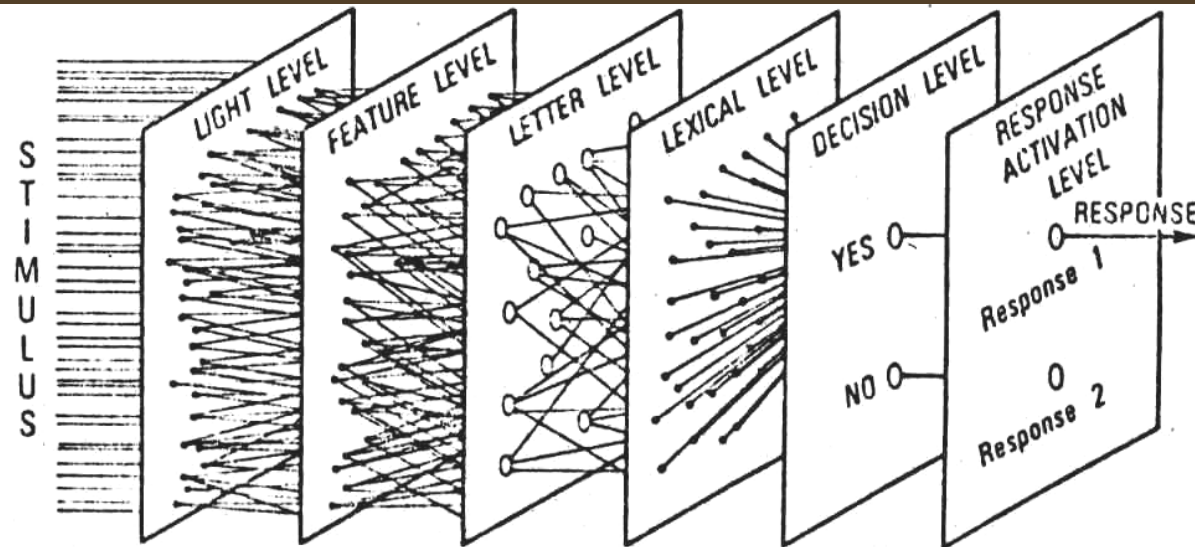
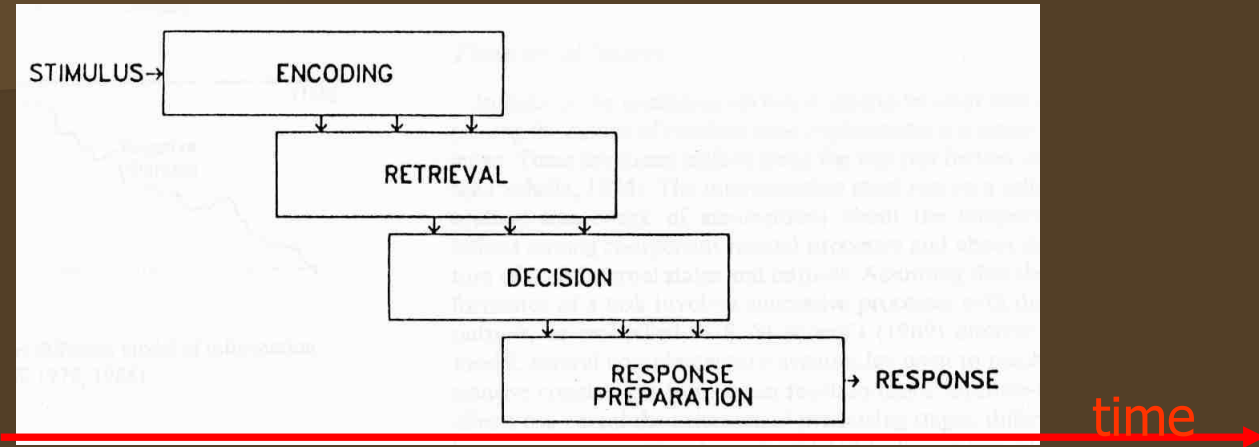
## ■ McClelland (1979)

- A series of processes cascading activation from an input level to an output level. Allows a given processing level to start with information transmission to the next stage before it has finished processing.



time →

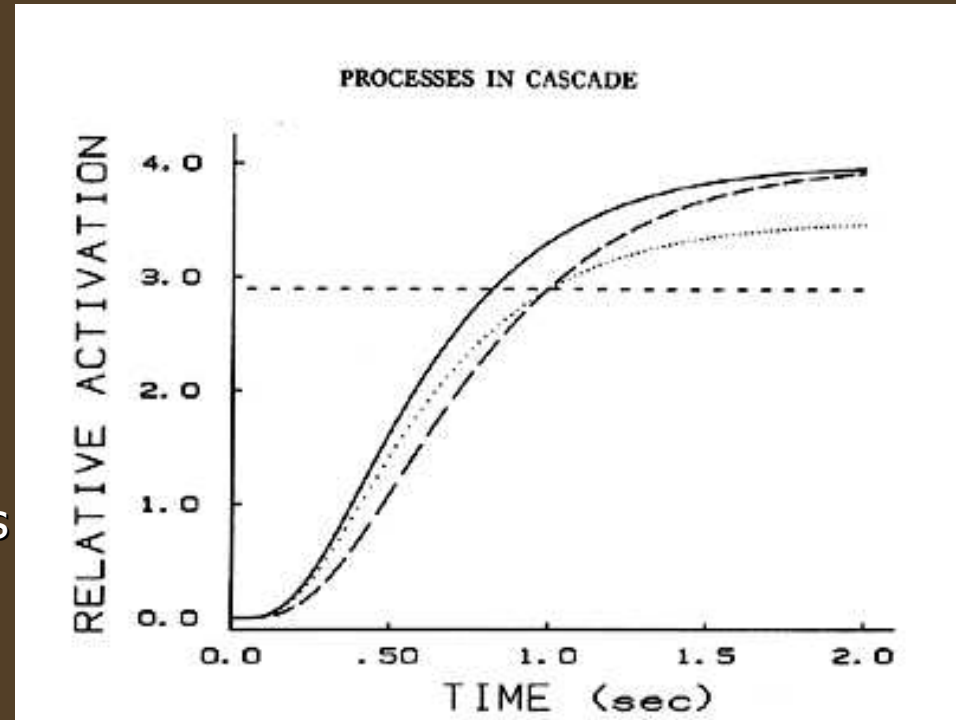
# McClelland's (1979) simulation of cascaded processes in a connectionistic model of a lexical decision task



Possible connections between units at different levels of processing in a simplified hypothetical system for determining whether a string of letters is a word or a nonword.

# Cascade model

- values in different units built up as a process of activation; activation functions follow an exponential function
- factor manipulations may affect either the rate of the process (rate of activation accumulation) or the asymptotic level
- → different outcomes possible when analysing the possible effects on two different factors



➤ simulations show that assumption of cascaded processes allows the emergence of additive effects of manipulations of individual processing stages

➤ additive effects may result e.g. if two factors affect the rate of two different processes

➤ different interpretation than AFM: interactions are possible if two manipulations affect two different processes  
→ factor a the rate of process 1, factor b the asymptotic component of process 2

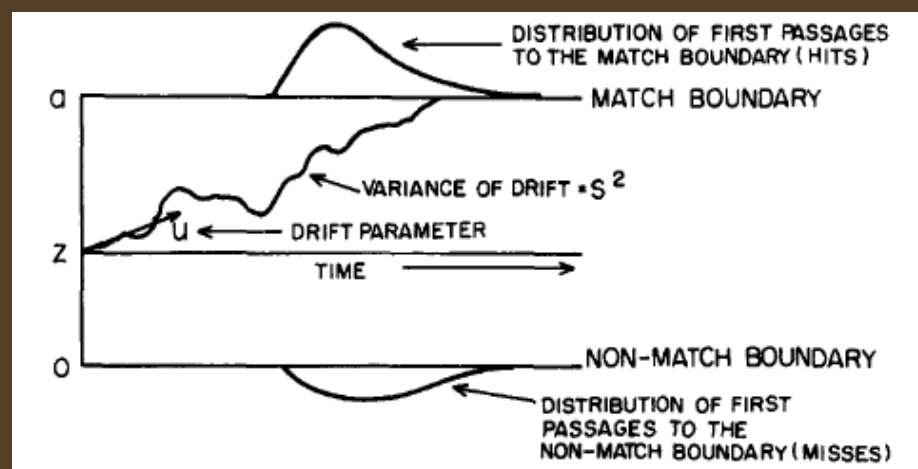
➤ **But:**

- additive effects restrict the number of possible architectures

- Collecting additional evidence by measuring other parameters about the mental chronometry (e.g., LRPs)

# Alternative theoretical presumptions: accumulation models

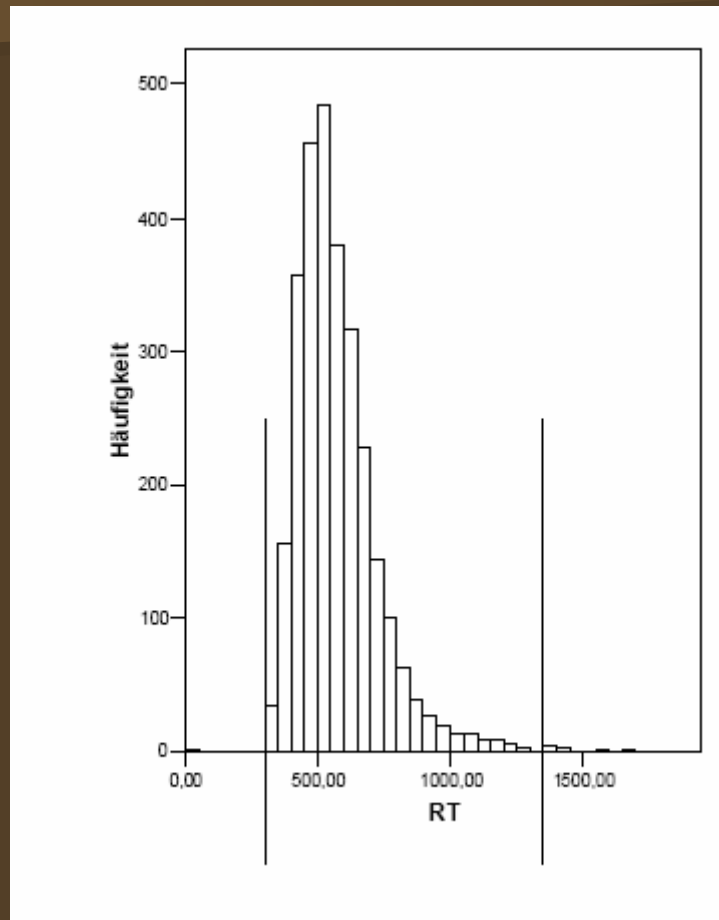
- Accumulation models:
  - decisions are built up with accumulation of information



Stochastic diffusion model of Ratcliff (1979); see also E.J. Wagenmakers

### 3. Problems and pre-conditions for sufficient use of RTs

- Clever design of the experiment – control of confounding factors:
  - psychological factors influencing RTs and their measurement (practice, alertness, sequence [order] effects..)
  - optimization of measurement (e.g. measurement of response force, execution time, determination of thresholds)
  
- Use of mean/median, outlier correction

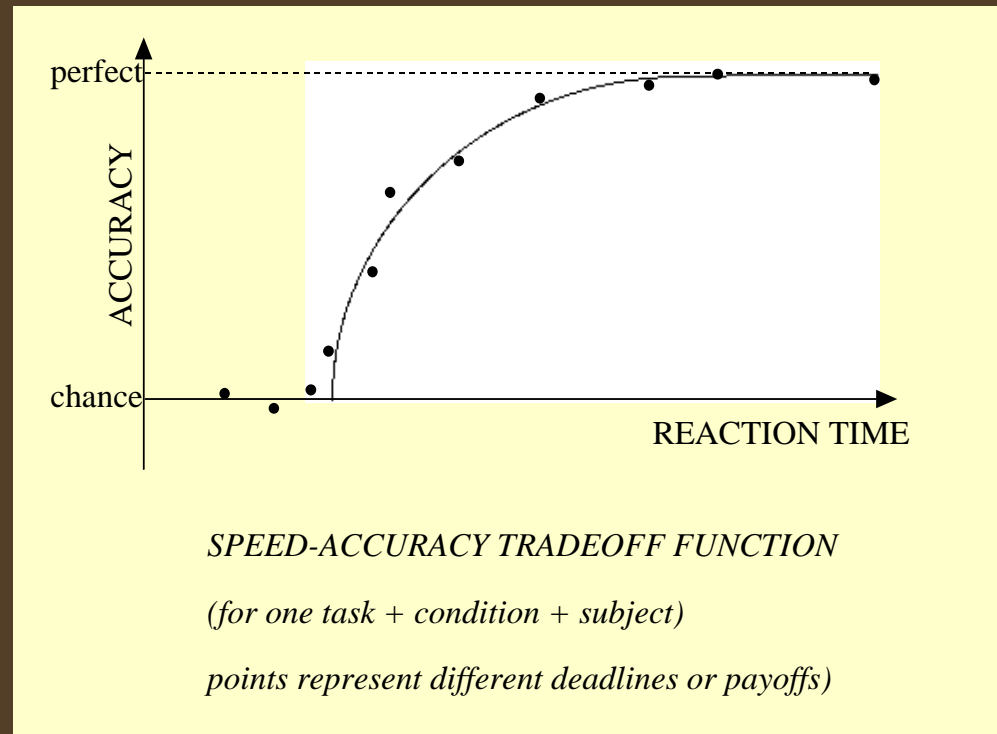


- Left skewed response time distributions
- Very fast RTs at the left and slow RTs at the right tails
- May be caused by factors not of interest in the experiment
- For example!
- What to do?
- Outlier procedure:
- Fix an upper and lower boundary
- (Mean  $\pm$  3SD)

### 3. Problems and pre-conditions for sufficient use of RTs

- Speed-accuracy trade-offs, consider error rate for interpretation
- analysis of response time distributions

Relation between response speed and accuracy can be influenced by instruction, deadlines, payoffs, "Respond-now"-signals



**You cannot get all what you want:**

**Either fast responses and many errors**

**or slow (relatively) but correct**

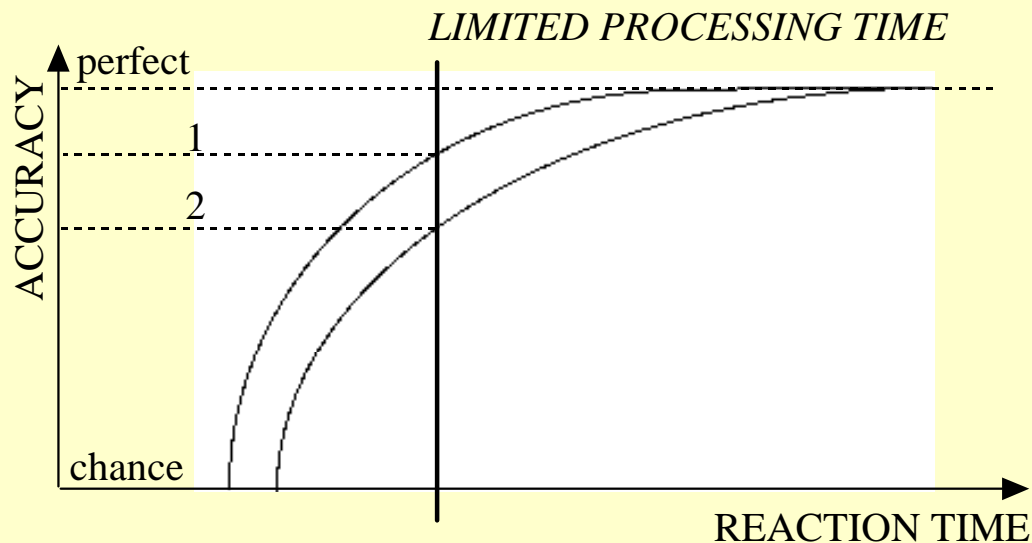
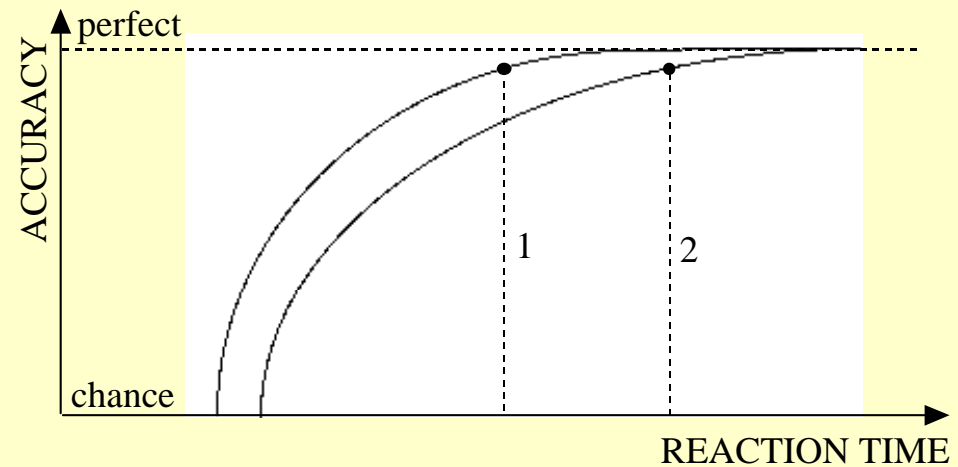
## Method 1:

Hold constant accuracy level of participants and compare response times

(5-8 % error)

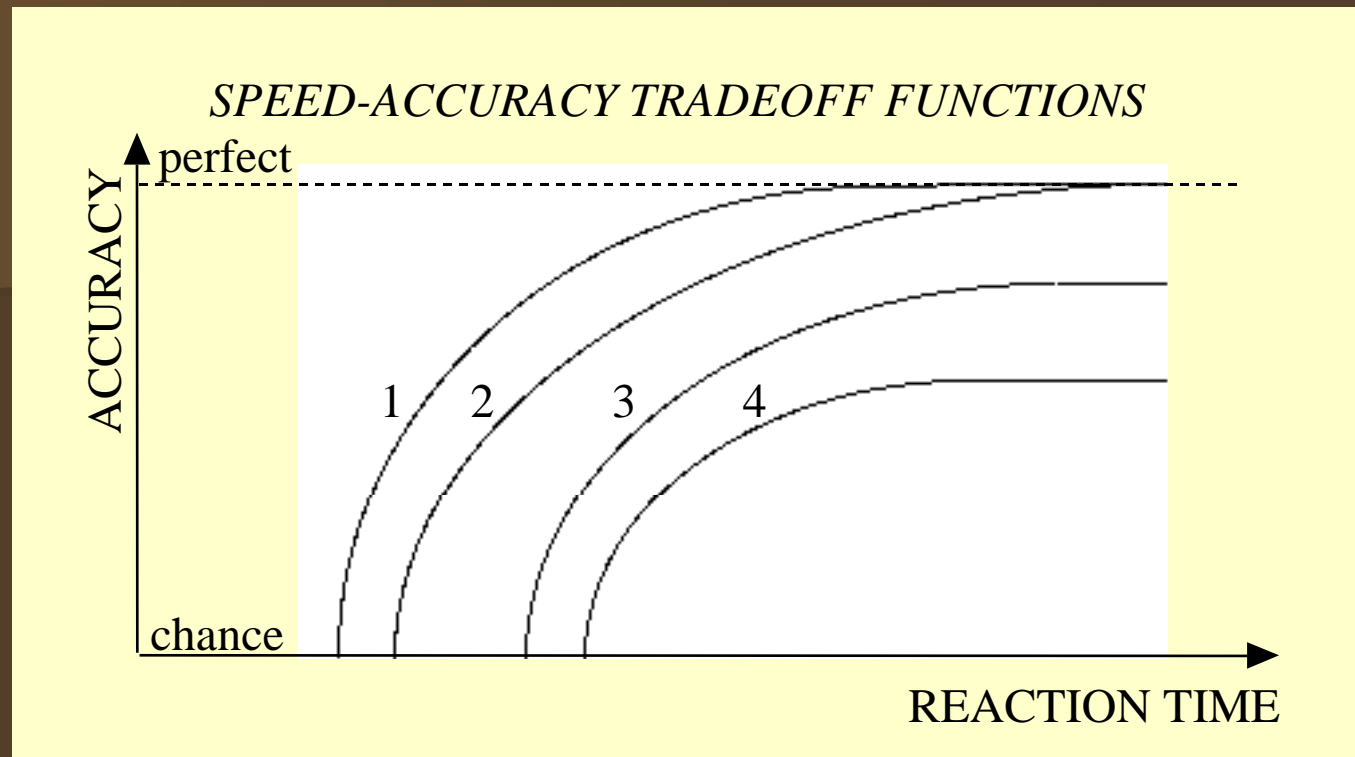
### REACTION TIME INSTRUCTIONS:

"Please respond as fast as you can while avoiding errors"



## Method 2:

Hold constant the maximum processing time & compare conditions

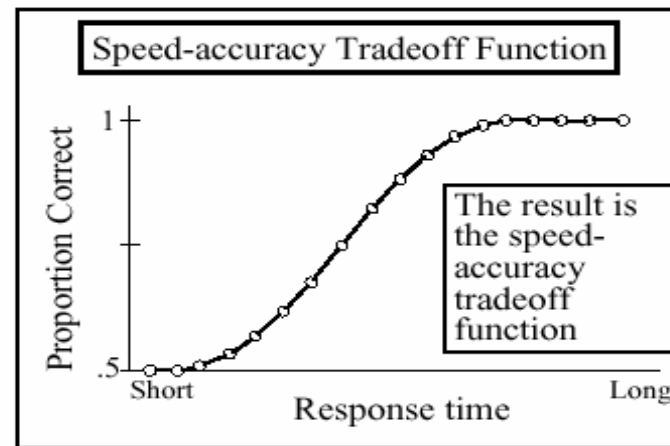
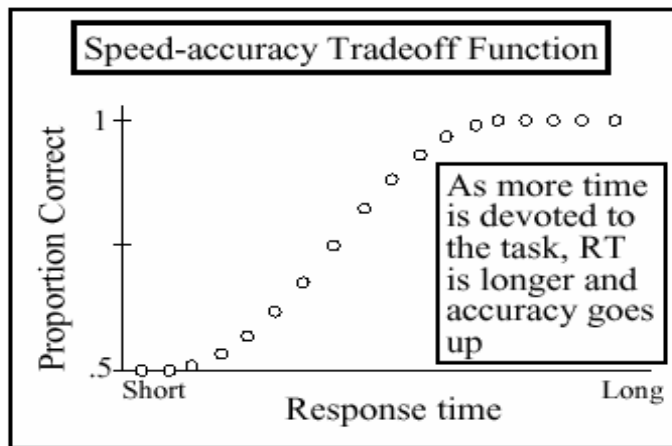
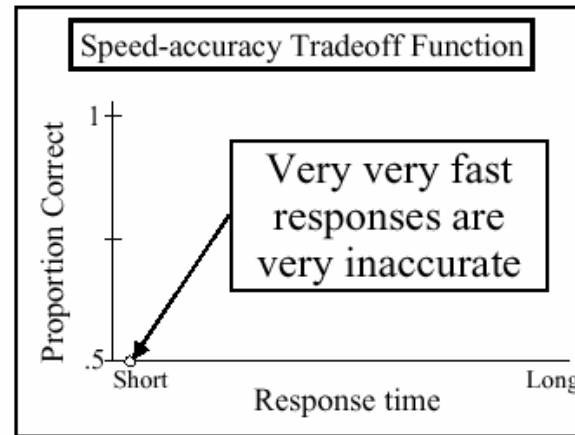
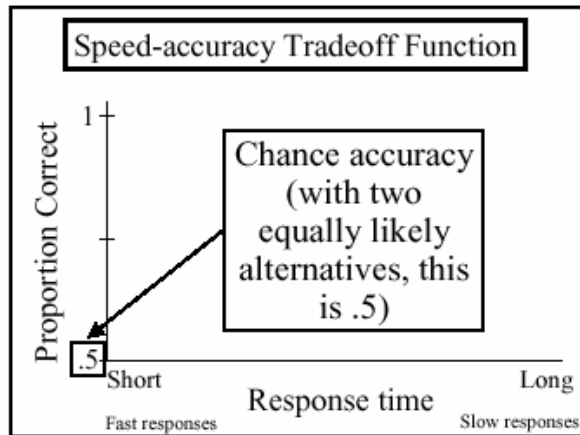


**Comparison of conditions** with different asymptotic accuracy:

=>necessary to measure the whole trade-off function by varying deadlines, payoffs, etc. (very effortful)

Difficulty relation:  $4 > 3 > 2 > 1$

# Speed-accuracy Trade-off (in detail)



# Software-Beispiele

<http://www.erts.de>

Name	Größe	Geändert
<UP--DIR>		02.03.01 20:52
350_20.voc	13273	26.02.01 16:37
750_20.voc	13273	14.08.00 16:44
900_20.voc	13273	15.06.00 15:02
989.res	349	02.02.01 12:43
99.res	727	27.02.01 11:20
998.res	0	26.02.01 15:55
erts.err	25875	21.08.99 18:41
erts.key	829	26.07.96 03:24
ertsdemo.exe	324556	22.10.99 03:29
experiment.zip	15404	02.03.01 17:42
false.pic	21748	12.10.00 15:11
fixpoint.pic	21750	09.10.00 16:33
fixsquar.pic	21750	01.02.01 15:02
mabotle.pic	21744	11.10.00 15:46
mabotri.pic	21744	11.10.00 15:49
matople.pic	21744	11.10.00 15:43
matopri.pic	21744	11.10.00 15:38
means.def	797	06.11.00 17:04
means2.def	1158	28.02.01 14:01
means3.def	885	08.02.01 12:22
meta350.exp	10019	02.03.01 20:54
meta5.exp	10015	02.02.01 12:03
neutbot.pic	21746	11.10.00 17:35
neuttop.pic	21744	11.10.00 17:21
pribotle.pic	21748	09.10.00 17:01
pribotri.pic	21748	09.10.00 17:54
pritople.pic	21746	09.10.00 16:33
pritopri.pic	21746	09.10.00 16:51
readme!.txt	1375	14.12.00 16:11
slow.pic	21747	20.10.00 16:44
test.exp	7967	15.12.00 16:01
verknüpfung mit diamon~1.lnk	405	02.03.01 17:40

.. <UP--DIR>  
C:\ERTS\DTMET>

<http://www.pstnet.com/products/E-Prime/>

The screenshot displays the E-Prime software interface with several windows open:

- Structure:** A hierarchical tree view showing the experiment structure: Experiment (BasicRT.es) -> SessionProc -> Instructions -> BlockList -> BlockProc -> TrialList -> TrialProc -> Fixation -> Stimulus -> Feedback -> Goodbye. Unreferenced E-Objects are also listed.
- Properties:** A table of properties for the selected Stimulus TextDisplay object.
- TrialList:** A summary window showing trial details and a table of trials.
- TrialProc:** A window showing the trial sequence: Fixation (green dot), Stimulus (ABC 123), and Feedback (star).
- Stimulus:** A window showing the current stimulus text: [Stimulus].

**Properties Table:**

(Name)	Stimulus
(About)	
(Property Pages)	
AlignHorizontal	center
AlignVertical	center
BackColor	white
BackStyle	opaque
BorderColor	black
BorderWidth	0
ClearAfter	No
DataLogging	Standard
Duration	10000
FontBold	Yes
FontItalic	No
FontName	Courier New
FontSize	18
FontStrikeout	No
FontUnderline	No
ForeColor	black

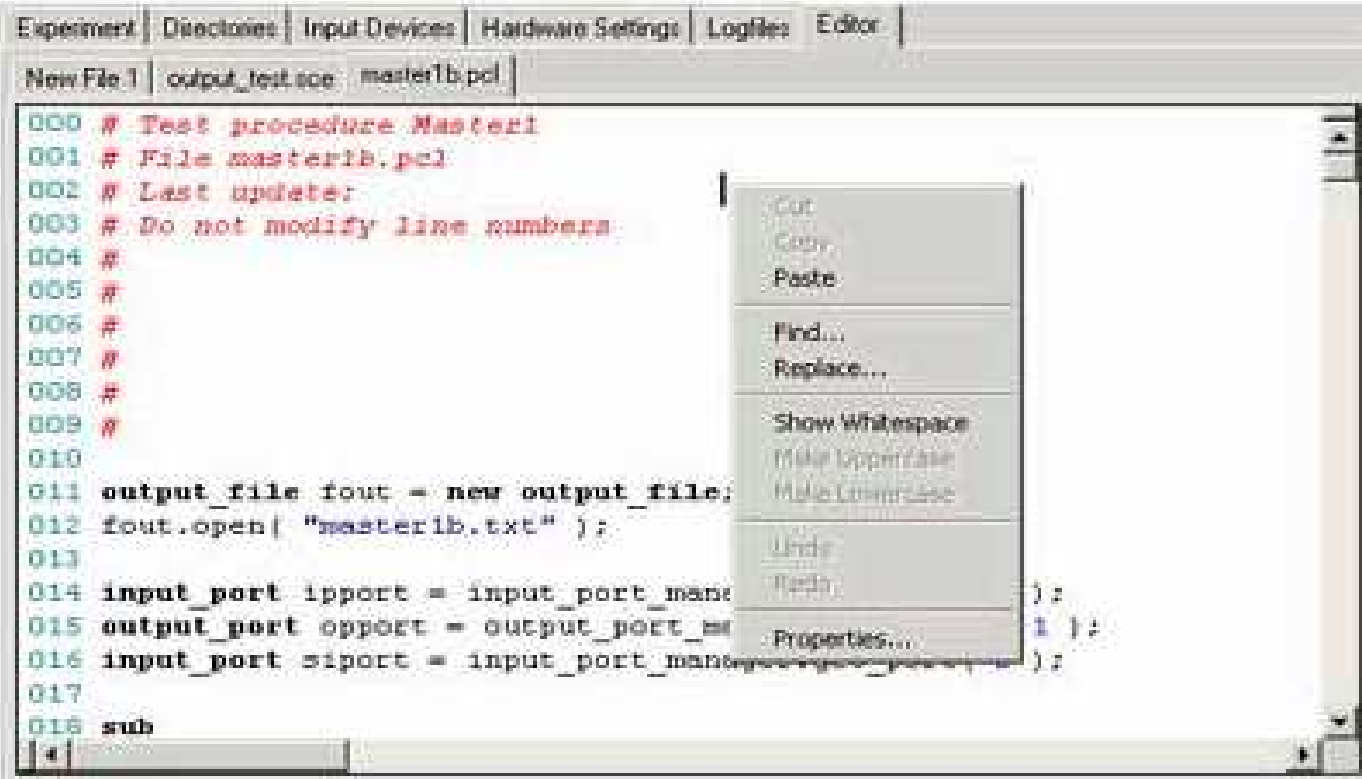
**TrialList Summary:**

4 Samples (1 cycle x 4 samples/cycle)  
1 Cycle equals 4 samples  
Random Selection

**TrialList Table:**

ID	Weight	Procedure	Nested	Stimulus	CorrectAnswer
1	2	TrialProc		X	1
2	2	TrialProc		Y	2

<http://www.neuro-bs.com/presentation>



The screenshot shows a software editor window with a menu bar containing 'Experiment', 'Directories', 'Input Devices', 'Hardware Settings', 'Logfiles', and 'Editor'. The title bar reads 'New File 1 | output\_test.soc: master1b.pcl'. The main text area contains the following Pascal code:

```
000 # Test procedure Master1
001 # File master1b.pcl
002 # Last update:
003 # Do not modify line numbers
004 #
005 #
006 #
007 #
008 #
009 #
010
011 output_file fout = new output_file;
012 fout.open( "master1b.txt" );
013
014 input_port ipport = input_port_man
015 output_port oport = output_port_ma
016 input_port siport = input_port_mant
017
018 sub
```

A context menu is open over the code, listing the following options: Cut, Copy, Paste, Find..., Replace..., Show Whitespace, Make Uppercase, Make Lowercase, Undo, Redo, and Properties...

At the bottom of the window, an error log displays the following messages:

```
Too many errors
C:\NBS\software\presentation\Presentation0.45\test_suite\master1b.pcl (14,20): Undefined identifier
C:\NBS\software\presentation\Presentation0.45\test_suite\master1b.pcl (14,39): get_port is not a member function of type
C:\NBS\software\presentation\Presentation0.45\test_suite\master1b.pcl (14,18): Assigning void to input_port
C:\NBS\software\presentation\Presentation0.45\test_suite\master1b.pcl (15,21): Undefined identifier
C:\NBS\software\presentation\Presentation0.45\test_suite\master1b.pcl (15,41): get_port is not a member function of type
C:\NBS\software\presentation\Presentation0.45\test_suite\master1b.pcl (15,19): Assigning void to output_port
```

# SPSS

all5\_cat2.sav - SPSS Daten-Editor

Datei Bearbeiten Ansicht Daten Transformieren **Analysieren** Grafiken Extras Fenster Hilfe

Berichte  
 Deskriptive Statistiken  
 Tabellen  
 Mittelwerte vergleichen  
**Allgemeines lineares Modell**  
 Gemischte Modelle  
 Korrelation  
 Regression  
 Loglinear  
 Klassifizieren  
 Dimensionsreduktion  
 Skalieren  
 Nichtparametrische Tests  
 Zeitreihen  
 Überlebensanalyse  
 Mehrfachantworten  
 Analyse fehlender Werte...

Univariat...  
 Multivariat...  
**Meßwiederholung...**  
 Varianzkomponenten...

	block	trial	prime	target	in	soa	key1	key2	fehler	rt1	rt2		
1	3	1	NBOT	MBOT				E4	2	430,40	621		
2	3	2	PBOTR	MBOT				E3	2	343,80	1183		
3	3	3	NTOP	MTOF				E4	2	401,60	1008		
4	3	4	PTOPL	MTOF				E3	2	331,50	476		
5	3	5	PBOTR	MBOT				E3	2	,00	492		
6	3	6	PBOTR	MBOT	1	1	E2	E4	2	339,80	493		
7	3	7	PTOPL	MTOF	3	2		E4	2	,00	1264		
8	3	8	PTOPL	MTOF	2	1	E2	E3	2	338,30	484		
9	3	9	NTOP	MTOF	2	2	E2	E3	2	347,00	1064		
10	3	10	NBOT	MBOT	2	1	E2	E3	2	310,80	436		
11	3	11	PTOPR	MTOF	3	1		E4	2	,00	460		
12	3	12	NBOT	MBOT	1	2	E2	E3	2	409,80	1011		
13	3	13	NTOP	MTOF	1	2	E2	E4	2	278,00	1196		
14	3	14	PBOTR	MBOTR	1	1			2	339,70	1096		
15	3	15	NBOT	MBOTR	1	3	1	E2	E4	2	359,80	493	
16	3	16	NTOP	MTOPL	1	3	2	1	E2	E3	2	384,10	511
17	3	17	PTOPL	MTOPR	1	2	2	1	E2	E4	2	356,80	470
18	3	18	NTOP	MTOPR	1	3	2	1	E2	E4	2	352,70	435
19	3	19	PBOTR	MBOTL	1	2	1	2	E2	E3	2	408,20	1118
20	3	20	PBOTL	MBOTR	1	2	2	2	E2	E3	1	379,70	0
21	3	21	PTOPL	MTOPL	1	1	1	2	E2	E3	2	361,80	1046
22	3	22	NBOT	MBOTL	1	3	2	2	E2	E3	2	494,20	1047
23	3	23	PTOPL	MTOPR	1	2	1	1	E2	E4	2	318,10	529
24	3	24	NBOT	MBOTR	1	3	2	2	E2	E4	2	387,80	1136
25	3	25	PBOTL	MBOTR	1	2	2	1	E2	E4	2	320,40	490
26	3	26	PBOTL	MBOTL	1	1	3	2		E3	2	,00	1233
27	3	27	PTOPR	MTOPL	1	2	2	1	E2	E3	2	302,70	468
28	3	28	PBOTL	MBOTR	1	2	1	1	E2	E4	2	382,10	492
29	3	29	PTOPR	MTOPL	1	2	1	1	E2	E3	2	308,00	507
30	3	30	NTOP	MTOPR	1	3	1	1	F2	F4	2	256,20	453

Datenansicht Variablenansicht