# Karl von Vierordt: His work and his legacy

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# This talk

- Consists of 3 parts (of unequal length)
- Firstly, I want to talk (briefly) about Vierordt's work in physiology and its sequelae
- Secondly, I want to tell you about some of the content of Vierordt's 1868 book *Der Zeitsinn nach Versuchen* (literally "The time sense according to experiments")
- Lastly, I want to discuss Vierordt's Law, with reference to some recent studies and recent ideas

# Acknowledgement


- To Dr. Helga Lejeune, friend and colleague of long-standing….
- ….but also native speaker of German, French, and Wallon
- …without which neither this talk nor the Lejeune and Wearden (2009) article on Vierordt would have been possible

# Karl von Vierordt ( July 1st.1818-November 22nd. 1884)

# Career

- Vierordt was a physician/physiologist
- He was educated at a number of well-known German universities including Heidelberg (where he received his Doctor of Medicine degree), Göttingen, and Berlin
- In 1842 and 1843 he worked as a physician for the Grand Duke's Own Infantry Regiment

# Tubingen

- The most extensive part of his career (from 1849) was spent at the University of Tubingen, where he was Professor of Physiology, and even Rector for a few years
- He also received an honorary degree from this university

# Physiological work

- Vierordt was what today we might call an experimental physiologist
- He carried our pioneering work in a number of areas….
- …and many of his inventions still exist in modern forms

# Spirometry

- Spirometry is the measure of lung function, for example lung capacity
- In 1845, Vierordt published a book describing his attempts to measure the volume of expired air
- Some of the measures he introduced (residual volume and vital capacity) are still in use today as indices of lung function

- Vierordt's spirometer

**Residual volume** is the volume of air remaining after maximal expiratory effort

**Vital capacity** is the greatest amount of air that can be forced from the lungs after maximal inhalation

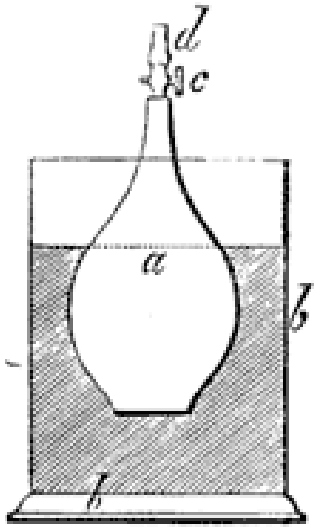



Figure 3. Expirator used by Vierordt.[1]

# Modern spirometer

# Oximetry

- Oximetry is the use of light to measure the amount of oxygen carried in the blood
- Vierordt attempted to measure this in 1874, but it took around another 50 years before practical devices were developed, after the First World War

# Here’s an oximeter you can buy from Amazon

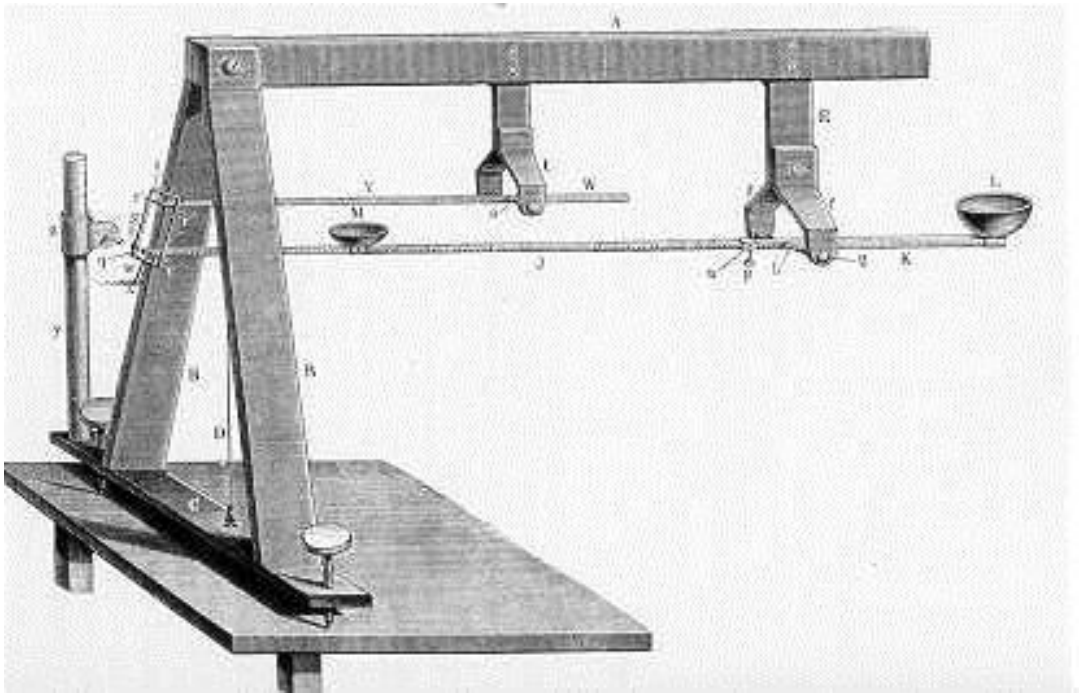
# In addition

- He attempted to count the number of blood cells in a sample, for the first time
- He invented a way of measuring postural sway
- But….his most important contribution to physiology and medicine involved the measurement of **blood pressure**

# Blood pressure

- Vierordt noticed that the application of pressure could prevent the arterial pulse being manifested
- The amount of pressure required was thus a measure of the blood pressure itself
- He developed an apparatus to measure this precisely

# The Sphygmograph



# Basic idea

- The basic idea was that adding weights to the cups would increase pressure on the arm, so eventually the pulse wouldn’t be manifested, and the weight could be measured
- The pulse was also measured using a kymograph, a rotating cylinder covered with smoke-blackened paper

# Later

- Vierordt's machine was improved by Marey (another important historical figure in physiology) so it could be portable
- And the general idea led to the development of the modern pressure-cuff, which was developed between 1881 and 1901 by various physicians

# Pressure cuff

# Psychological research

- Given that one of the themes of Vierordt's work was making outwardly observable, by non-invasive means, internal *physiological* processes, it's maybe no surprise that he turned to the ultimate challenge of this sort, making *psychological* processes outwardly observable….i.e. experimental Psychology
- Vierordt seems to have been one of the very earliest experimenters in this area

# Time-line…

- Vierordt was conducting psychological research, on auditory and visual perception, before 1852, as a publication from his laboratory dates from that year
- In contrast, the publication of Fechner's *Elements of Psychophysics* was 1860

# ..continued

- Vieordt is credited with the invention of the “method of right and wrong cases” which was later developed by Fechner as the “method of constant stimuli”
- In Vierordt’s original form, this was a pair comparison technique where the participant received two consecutive stimuli, and had to make some relative judgement, such as which was louder or longer, then another pair would be received, and so on

# Coincidence?

- Wilhelm Wundt was a student of medicine in Tubingen in 1851 (his uncle was a medical professor there): Vierordt was almost certainly conducting psychophysical experiments at this time
- Did the work of the professor have some influence on the student?

# *Der Zeitsinn nach Versuchen*

- In 1868, Vierordt published *Der Zeitsinn nach Versuchen*, literally “The Time sense according to Experiments”, which Lejeune and Wearden (2009) translated as “The Experimental Study of the Time sense”
- This did not report the first experimental studies of time perception (these appear to have been by Höring, Vierordt’s student, of whom more later, in 1864, Mach in 1865, and Camerer, another Vierordt student, in 1866), but the quantity of data in *Der Zeitsinn* was many times more than everyone else’s up to that time, put together

# *Der Zeitsinn*

- The very title of Vierordt's work is important, as a dispute at the time (still with echoes today) is whether time judgements were derived from a "time sense" (*Zeitsinn*), or whether they were necessarily secondary, derived from the perception of something that was non-temporal

# Experimentation

- The data collected in *Der Zeitsinn* come from experimental studies in which Vierordt himself, or sometimes his pupil Höring, was the sole experimental participant
- Höring not only carried out time perception studies to qualify for a medical degree, but his thesis work has the oddity that Höring was the **participant** and not the experimenter (who was Vierordt)
- The data were derived from very extensive experimentation, often involving hundreds of experimental trials carried out over many days

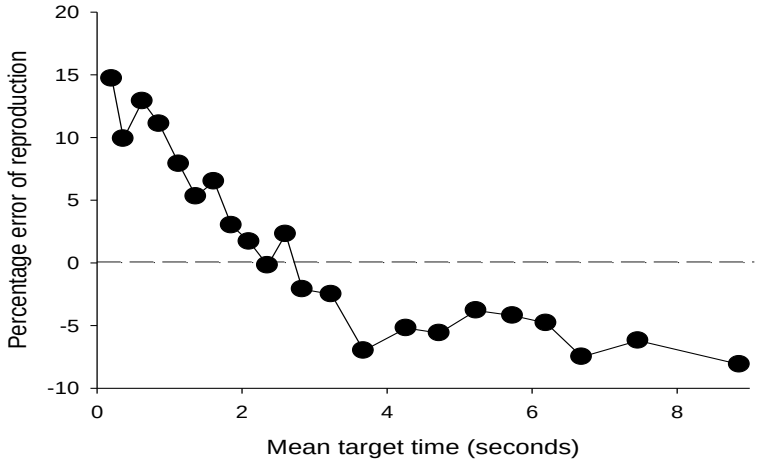
# Reproduction method

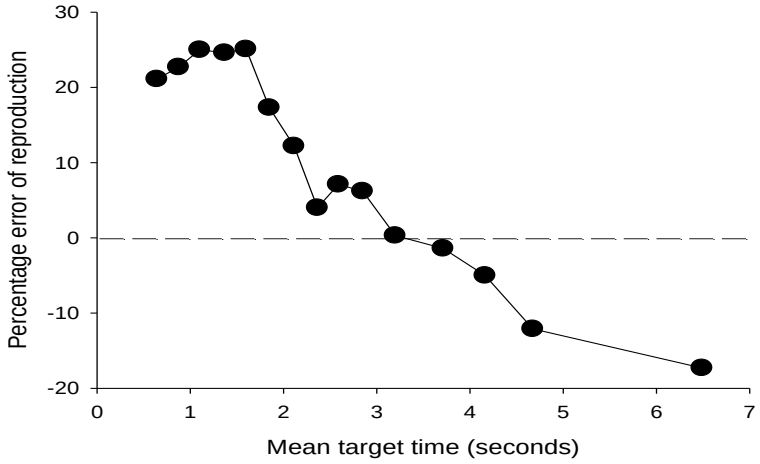
- I first show you some data from two experiments using a reproduction method (a technique which features prominently in *Der Zeitsinn*)
- Two taps (on a glass plate) define a target time interval and the participant must make a response so that the time between the second tap and the response is equal to the time between the two taps

# Measures used

- The measure used is the reproduction expressed as a percentage of the target time minus 100, so positive values indicate that the reproduction was longer than the target, negative values that it was shorter, with accurate reproduction being zero (shown by a dashed line in the figure)
- Vierordt was the participant

# Vieordt's Law in reproduction



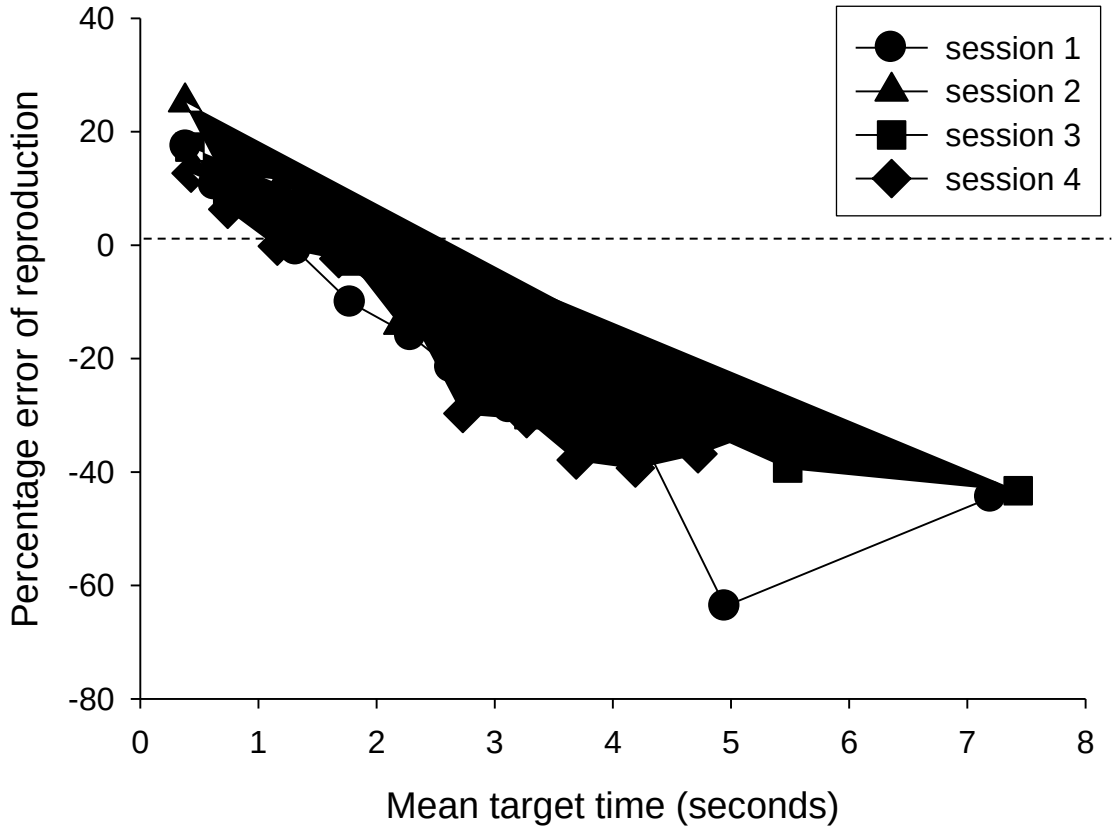
# Vierordt's Law

- The data conform to Vierordt's Law
- This is the proposition that short intervals of time are judged as longer than they are, whereas long intervals are judged as shorter, with an *indifference point,* where intervals are judged correctly, somewhere between the two

# Indifference points

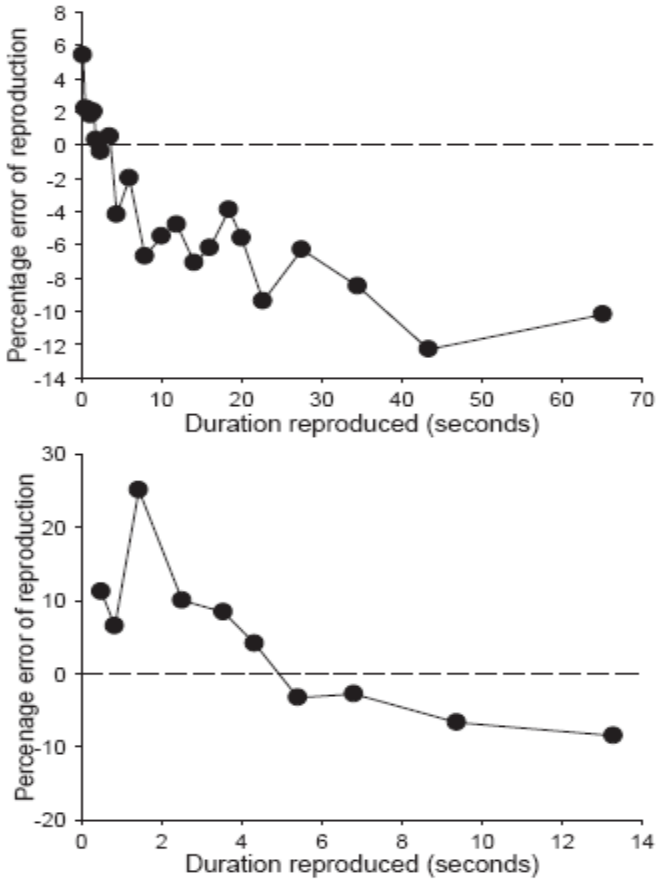
- The upper panel of the next slide shows data from Dr. Höring, who conducted 4 sessions of reproduction
- Notice that his indifference point is stable from one session to another

# Indifference points



# Vierordt's Law

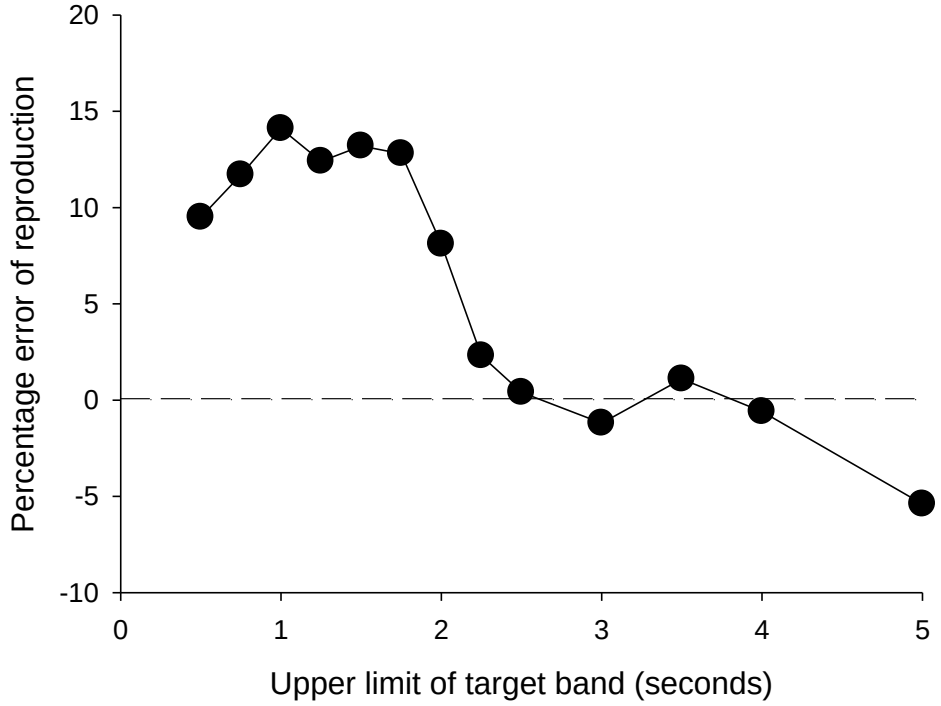
- Vierordt's law quite general in reproduction, and even holds for the reproduction of longer durations, as the next slide shows


Percentage error of reproduction
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
0
10
20
30
40
50
60
70
Duration reproduced (seconds)
Percenage error of reproduction
30
20
10
0
-10
-20
0
2
4
6
8
10
12
14
Duration reproduced (seconds)

# Finally…

- As a final example, the next slide shows reproductions of an interval defined by two tactile stimuli (touches on the arm)
- Vierordt is the participant

# Reproduction of intervals defined by touches on the arm



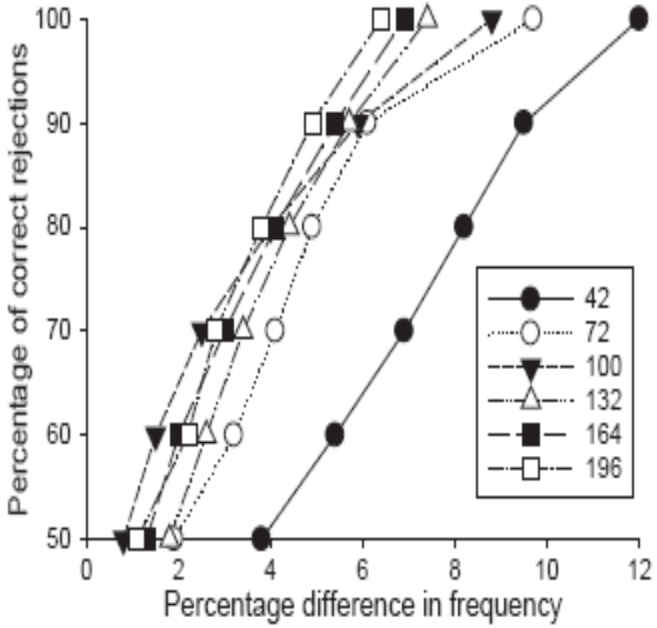
# The story so far

- In reproduction of different sorts of durations, and with different modalities defining the target interval, short intervals are reproduced as longer than they are, where the longest intervals are reproduced as shorter
- There's always an indifference point (and it's stable across sessions with the same participant and method), but its location varies depending on the experiment
- Between 2 and 3 seconds is a common value, but it's sometimes higher than this

# Other experiments

- *Der Zeitsinn* doesn't only report reproduction studies
- In another experiment, using a discrimination method, Vierordt determined the threshold for detecting that the rates of metronome ticks in two successive periods were different
- This used the "method of right and wrong cases"

# Discrimination data



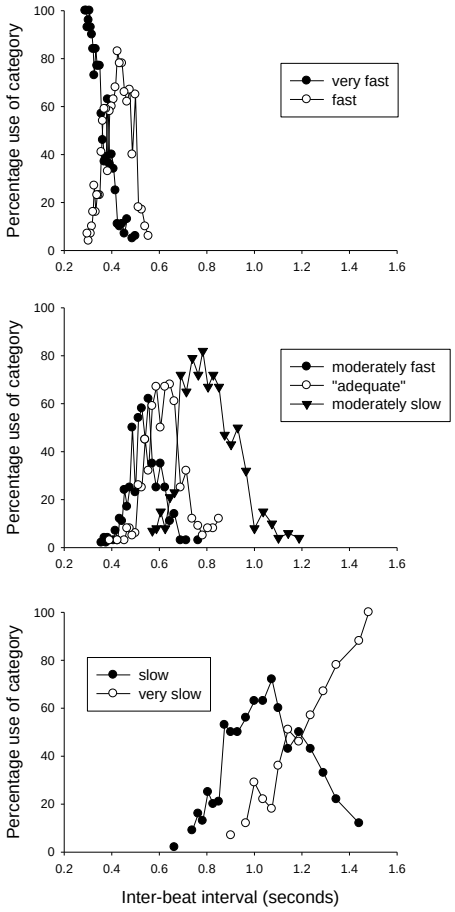
# Comments

- Note that the percentage difference to obtain some degree of correct responses (e.g. 80% correct) doesn't vary much with frequency except when this is very slow (42 beats per minutes: 1.43 seconds/beat)
- Performance is distinctly worse for this slow rate

# Categorical timing

- In another experiment an assistant played a metronome at some tick rate for a while, and then Vierordt classified the tick rate into 7 categories (very slow, slow, moderately slow, “adequate”, moderately fast, fast, very fast)
- Notice the “magic number 7” here (which wasn’t remarked on until nearly 90 years later)
- 1875 trials were conducted over 28 sessions

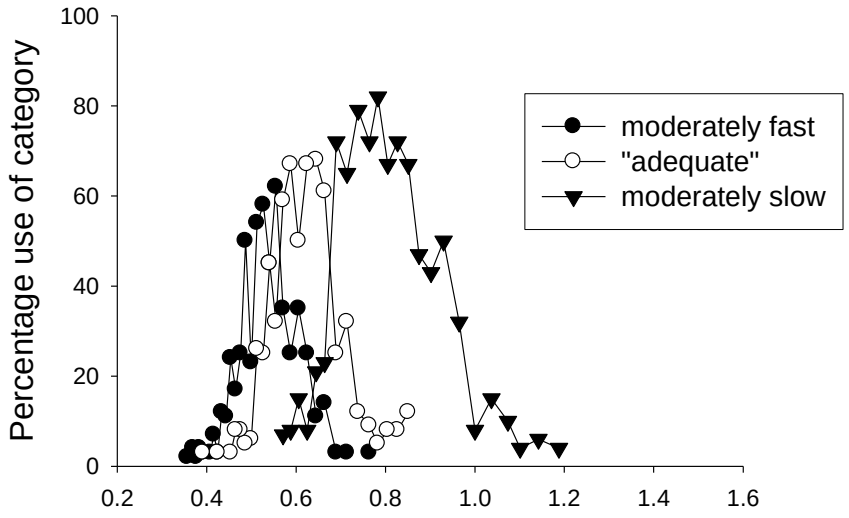
# Categorical timing

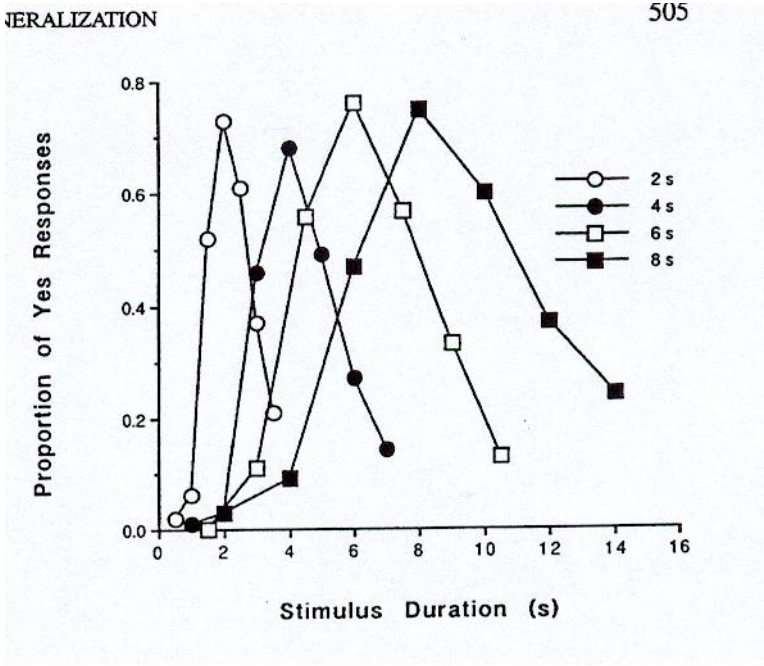


# Things to note

- The categorization functions varied in an orderly way with inter-beat interval
- The inverted-U-shaped functions increased in width as duration increases
- This is an early example of scalar-type timing, as the next slide shows

# Vierordt (1868) and Wearden et al. (1997)

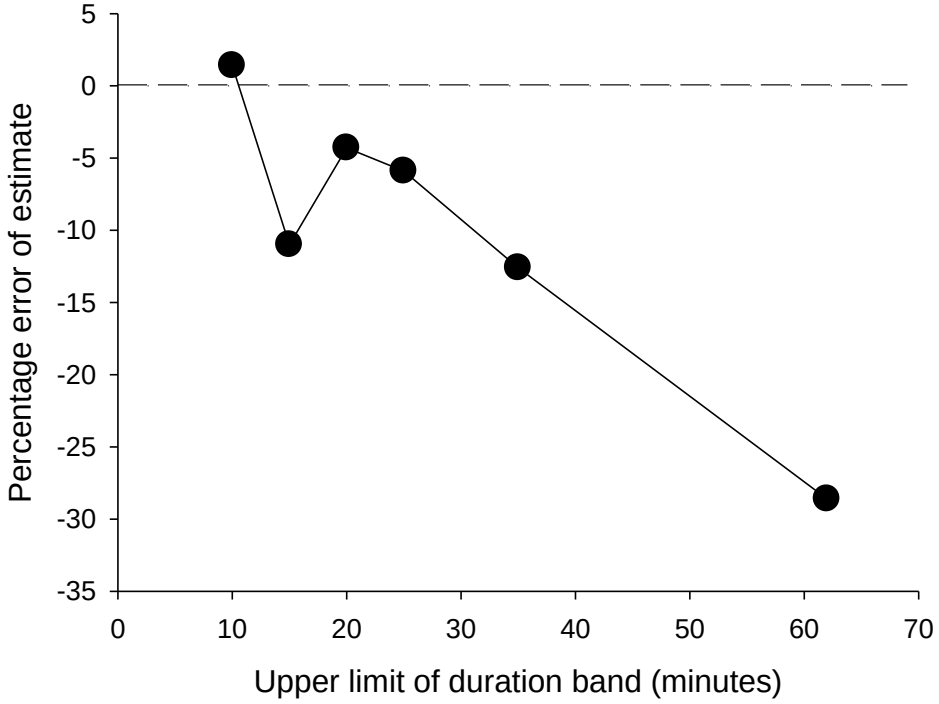


# Estimation of long durations

- In the final experiment  presented here, which shows data which are virtually unique in time Psychology, Vierordt estimated long intervals of time (up to over 60 minutes)
- The exact procedure isn’t clear, but he seems to have spent various periods “carrying out routine tasks in the laboratory” then he estimated how long they lasted before checking the clock time

# Verbal estimation of long durations



# Comments

- The Vierordt Law effect can be seen in estimation, although most intervals were underestimated, in some cases severely

# Other ideas

- As well as a large body of experimental work, of which I've provided you only with a sample here, Vierordt made a large number of other observations about time perception, many of them original at the time
- One was the comment that auditory stimuli appeared to last longer than visual ones, something that's the subject of research even today (e.g. there's a 2006 paper by me in *QJEP,* and even more recent ones). His mention of this phenomenon long precedes that of Guyau (1890), who is usually said to be the first person to note the effect

# Later studies of the indifference point

- As you've seen Vierordt found indifference points in a number of different places, but the location was often 2 or more seconds
- The location of the indifference point later became the subject of more research, and assumed an almost mystical significance for some researchers
- This was because it was supposed to define the "psychological present" or "perceived present"

# Présent perçu

- One idea, discussed in Fraisse's well-known *Psychology of Time* (various editions, but the English translation of 1964 is best-known in the UK) is that the indifference point defines the *présent perçu,* an interval that represents the experienced present (with events outside this range being in the past or future), and within which events that extend over some time period (Fraisse's example is the cry of a bird) are perceived as a unity

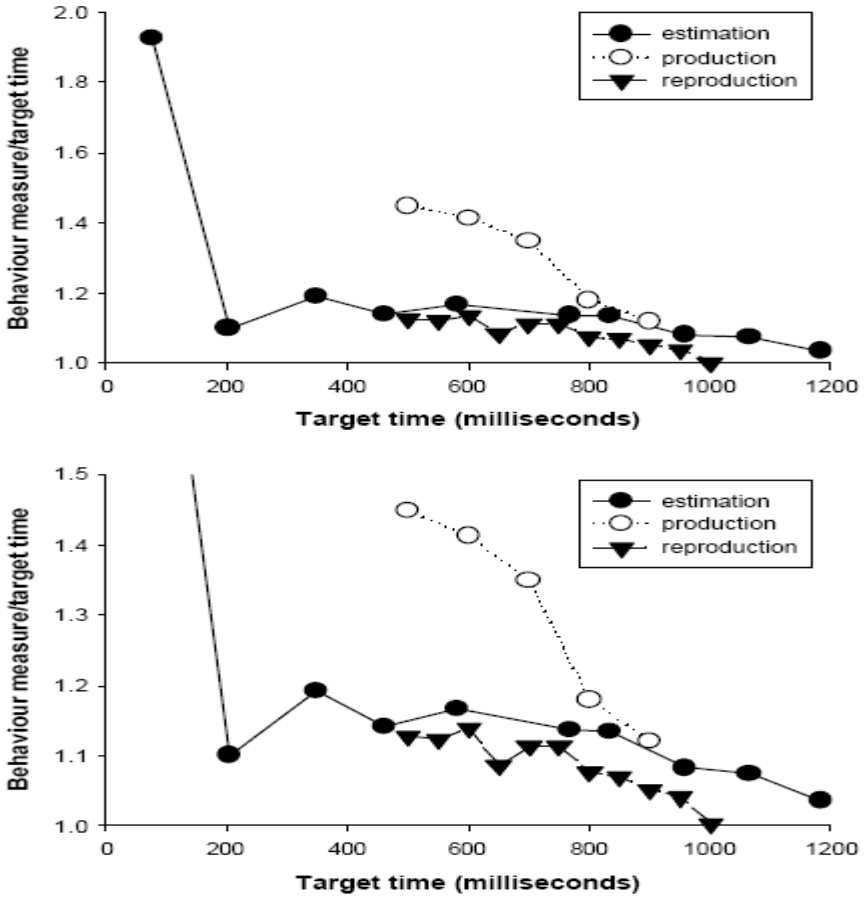
# Later German research

- Vierordt's discovery of the indifference point led to much research in other 19th. Century German Psychology laboratories, such as that of Wundt
- The favoured value for the indifference point from this research was around 0.75 seconds, a value much shorter than Vierordt often found

# Some issues relating to Vierordt's Law

- **Question 1**: **Does it only work with reproduction?**
- No: You can get it with all the "classic" procedures, such as estimation and production
- The next slide shows data, with the two panels showing the same data but on different scales

# Estimation, production, and reproduction



# Comments

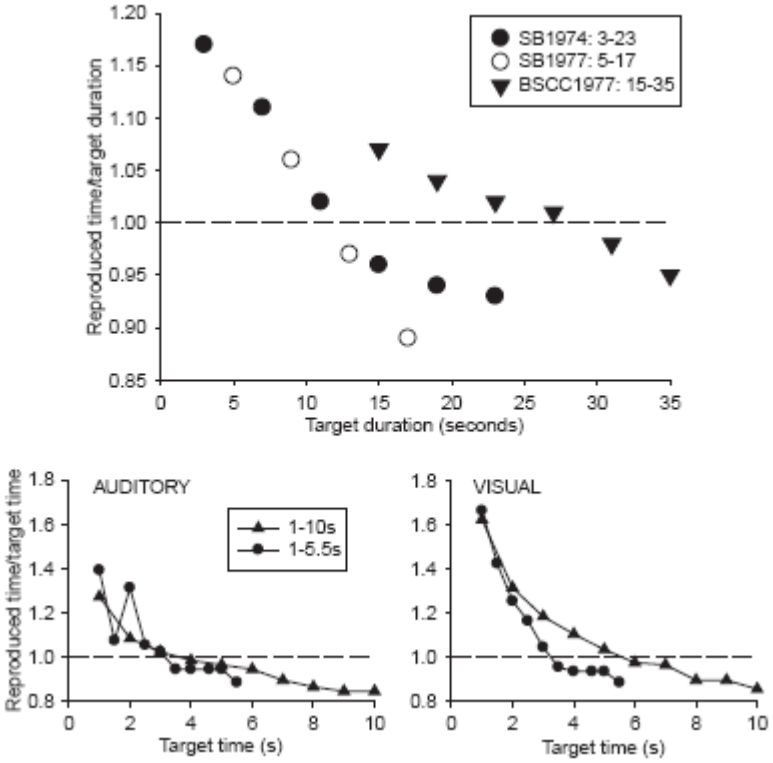
- The data are just fairly random ones collected by me over the years but are completely typical
- In estimating intervals without counting, it's very common for Vierordt-like effects to occur: i.e. the estimate decreases as a fraction of the target time as the time increases

# But…

- You don’t always get it even with reproduction
- Studies by Woodrow (1930, 1933) used production of a range of intervals (0.2 to 30 s)
- “There is no even remotely uniform tendency for constant errors to change from positive or negative at…any….interval”

# The indifference point

- **Question 2: what determines the location of the indifference point?**
- How does it vary with the range of intervals used?
- Sometimes it seems to track some central tendency of all the intervals presented
- Look at the upper panel of the next figure

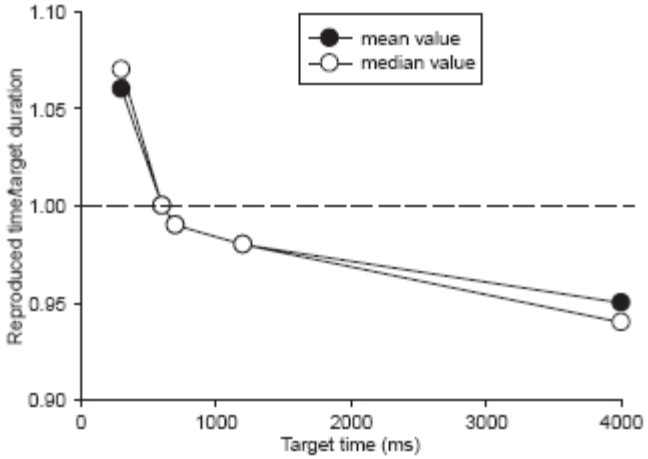

SB1974: 3-23
SB1977: 5-17
BSCC1977: 15-35
Reproduced time/target duration
Target duration (seconds)
AUDITORY
1-10s
1-5.5s
Reproduced time/target time
Target time (s)
VISUAL
Target time (s)

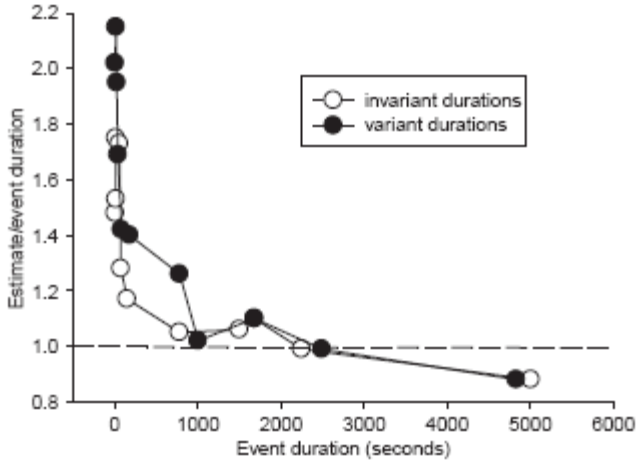
# But it doesn’t always

- Look at the bottom panels: the indifference point seems to track some sort of central tendency when the stimuli are visual but not when they’re auditory

# In addition

- Vierordt's Law is sometimes obeyed when people only judge a single interval, or even have a single trial
- In the upper panel of the next slide (data from an experiment by Woodrow, 1934), people only reproduced one interval, although they did it more than once. In the bottom panel (data from Yarney, 2000) people only had 1 trial, and the interval estimated differed between them


mean value
median value
Reproduced time/target duration
1.10
1.05
1.00
0.95
0.90
0
1000
2000
3000
4000
Target time (ms)


invariant durations
variant durations
Estimate/event duration
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0
1000
2000
3000
4000
5000
6000
Event duration (seconds)

- **Question 3: why is Vierordt's law obeyed at all?**
- To address this question, we perhaps need to look at timing models, and other perceptual models, more generally.

# Links with contemporary timing research

- Explaining why behaviour often conforms to Vierordt's Law is a major theoretical problem for contemporary models of time perception such as *scalar timing theory* (SET)
- For example, it's compatible with non-linear temporal scaling, but other data (although not all) support a linear time scale or something close to it

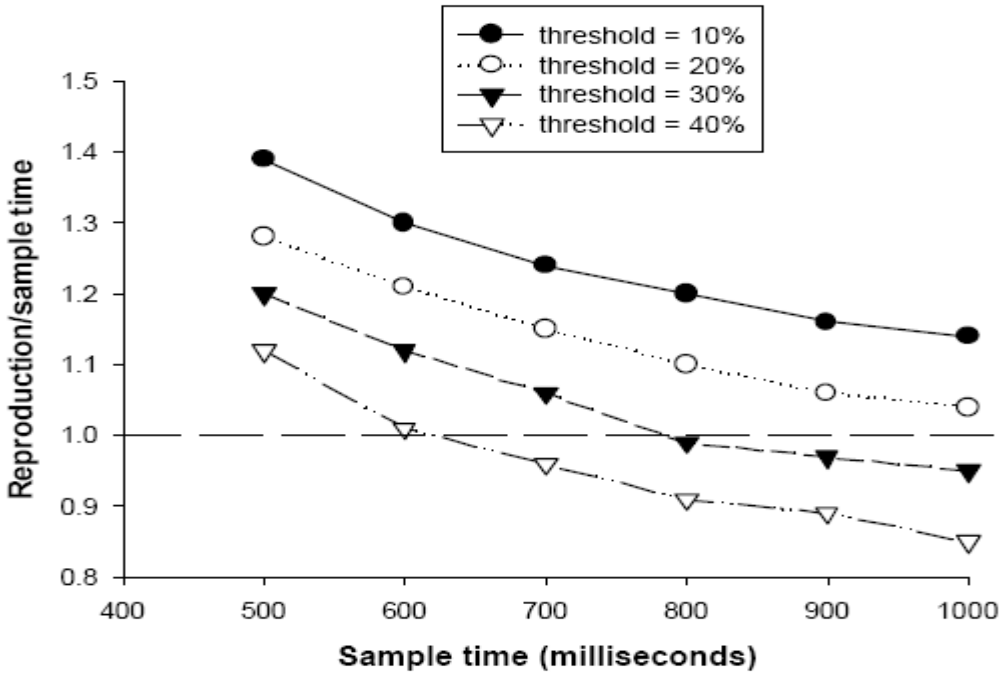
- However, it’s possible to reconcile Vierordt’s Law, at least in some cases, with linear time scaling quite easily
- Wearden (2003) presented a model of reproduction which was consistent both with Vierordt’s Law and was compatible with SET

# Reproduction model

- The basic idea is that the participant's representation of the target, *t*, is on average accurate
- The participant initiates a response at some time which is "close enough" to the target (e.g. 70% of it, in general at *ct*), but the response takes some absolute time, *d*, to generate
- So the total reproduction time is $ct + d$
- If $c = .7$ and $d = 300$ ms, then a *t* of 500 ms will be reproduced as 650 ms, but a *t* of 1000 ms will be reproduced accurately, and a *t* of 2000 ms reproduced as 1700 ms

# …continued

- With “reasonable” values for *c* and *d*, the model predicts indifference points at the lower part of the range found by Vierordt, but has difficulty with much longer values
- The indifference point, of course, has no special significance here, but the later typical value of 0.75 s is compatible with “reasonable” *c* and *d* values, so perhaps it comes from a combination of decision threshold (*c*) and response time (*d*) which haven’t changed much since the 19th. Century


threshold = 10%
threshold = 20%
threshold = 30%
threshold = 40%
Reproduction/sample time
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
400
500
600
700
800
900
1000
Sample time (milliseconds)

# Basic problem

- The basic problem for this model is that Vierordt's Law is usually found in reproduction, production without feedback, and verbal estimation of duration, according to recent research
- The reproduction model can't apply to verbal estimation, where there's no timed motor response
- However, the reproduction model will work in situations where people only receive one interval, like those of Woodrow (1934)

# The “relativistic” approach

- A popular account of Vierordt’s Law has been what might be called a “relativistic” approach
- This proposes that judgements of individual time intervals show Vierordt characteristics not because of the way that they are individually timed (e.g. non-linear time scaling, motor factors…), but because of their values relative to other intervals used

# “Local” relativity

- One proposal might be “local” relativity, for example the idea that judgement of an interval in a set is affected only by the value of the previous interval presented
- For example, the interval on trial *x* is “pulled towards” the interval on trial *x – 1*
- If there are *n* intervals in the set, then when the shortest one is presented it’s likely that the previous one has been longer, so that increases its judged duration; when the longest has been presented it’s likely that the previous one has been shorter, so that decreases its judged duration, and so on

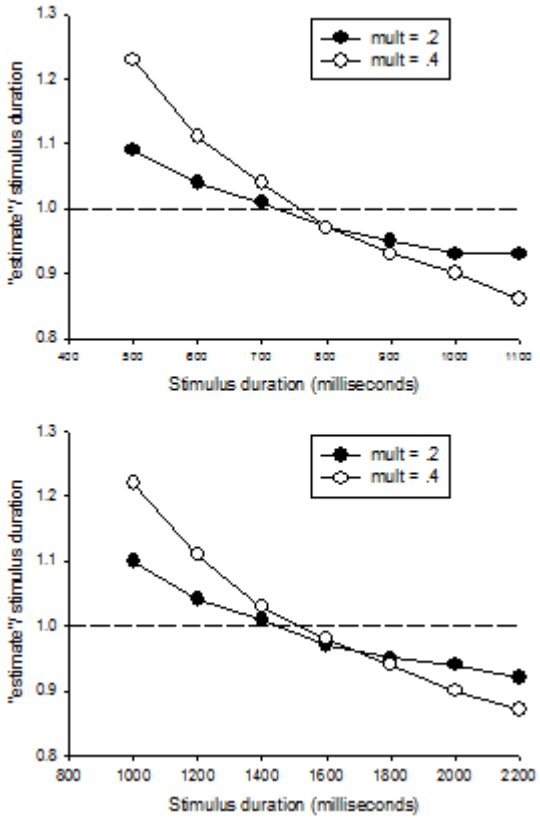
# A “one-back assimilation” model

- This sort of idea can easily be formalized
- Let’s suppose that a model calculates the difference in duration between the current interval *t(n)* and the previous one *t(n – 1)*
- Call this difference $d = t(n-1) - t(n)$
- The difference is multiplied by *mult* which is a kind of weight, then the estimate of *t(n)* is just $t(n) + mult*d$

# Model

- The idea here is that each duration is “pulled” towards the previous one
- The weight, *mult*, expresses the “force” of the pull
- All durations were transformed into values picked from a Gaussian distribution with mean *t(n)* and a cv of 0.2
- This just produces trial by trial scalar variance

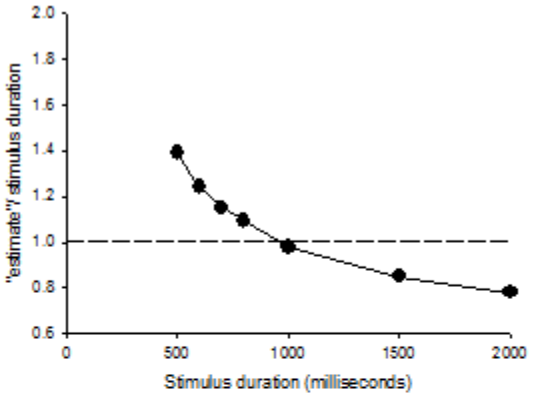
# Simulation

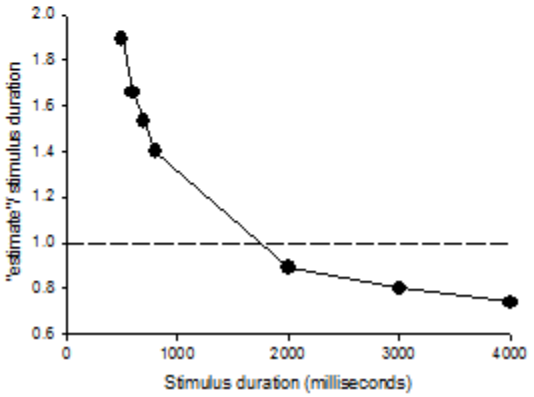

mult = .2
mult = .4
"estimate"/ stimulus duration
1.3
1.2
1.1
1.0
0.9
0.8
400
500
600
700
800
900
1000
1100
Stimulus duration (milliseconds)
mult = .2
mult = .4
"estimate"/ stimulus duration
1.3
1.2
1.1
1.0
0.9
0.8
800
1000
1200
1400
1600
1800
2000
2200
Stimulus duration (milliseconds)

# Comments

- Vierordt's Law is obeyed, and the location of the indifference point depends on the range of intervals used
- Higher *mult* values produce stronger Vierordt-like effects, as you'd expect
- The next slide shows the effect of adding longer durations to a common set of shorter ones

# Simulation results



# Comments

- Having longer values in the set affects the estimates of the consistent subset of shorter ones (500 to 800 ms), again, as you'd expect

# Woodrow (1930)

- As you'll recall, Woodrow didn't find any Vierordt-like effects in his 1930 work, but then….
- "The intervals …..varied from 0.2" to 30.0"…. Each interval was used alone on any one day "
- So, the one-back assimilation model wouldn't predict Vierordt-like effects in this case

# However…

- …the model depends on the relations between consecutive intervals being a sort of **assimilation** rather than **contrast**
- Furthermore, models like this could be more complicated, taking into account the *m* previous intervals (*m* > 1)
- This leads to what we might call “global relativity”: now the determining factor in the judgement of interval *n* is some characteristic of the population of intervals from which interval *n* is drawn

# Hollingworth (1910)

- An early worker who developed this idea to account for the location of the indifference point, and even specifically mentioned Vierordt's work, was Hollingworth (1910)
- Hollingworth was a Professor at Barnard College, and was elected President of the APA in 1927
- Here's a quote….

- “The tendency throughout [i.e. up until 1910] has been to infer that the I.P. disclosed in any particular experiment was in some way an absolute quantity…” (p. 461)
- Hollingworth instead proposed that “The I.P is relative – not absolute. It is a function of the series limits of the stimuli employed”.

# Central tendency

- This obvious implication of this is that the location of the indifference point depends on the "population characteristics" of the intervals used, maybe the mean or some other measure of central tendency, perhaps also the range
- So, putting it crudely, short intervals are judged as longer than they really are because they're shorter than the mean; longer intervals as shorter, for the opposite reason

# Examples

- You've seen examples of this in some of the data discussed earlier: the indifference point seems to vary with the values of the set of intervals used
- But you've also seen data for which this can't be true, because people have only judged one value, or even had one trial

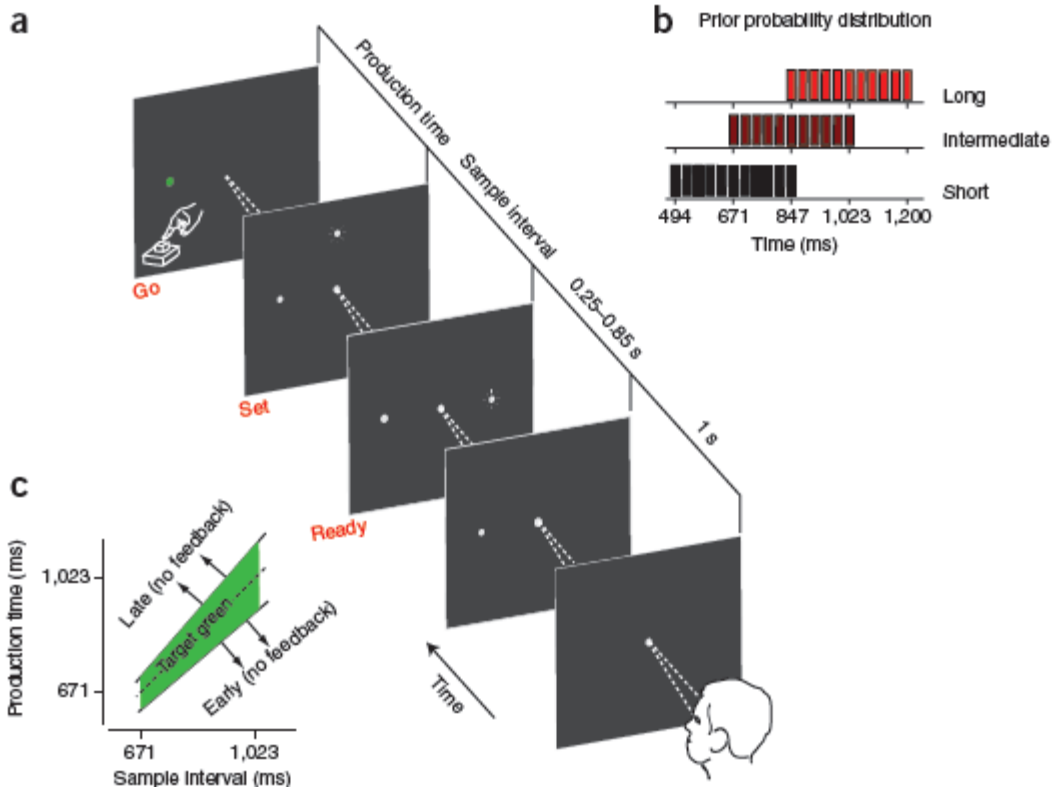
# Questions?

- Although this idea of some sort of “drift” towards the “central tendency of judgement” fits some data (and it doesn’t only apply to time judgements)….
- What’s the psychological mechanism behind it?
- Why doesn’t it work the other way around (as something like Adaptation level theory might suggest)?

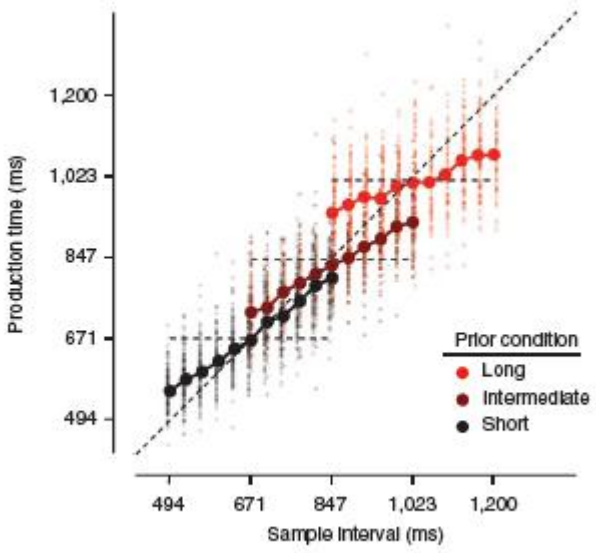
# Jazayeri and Shadlen (2010)

- A recent version of a global relativistic account of Vierordt effects, as well as temporal reproduction performance more generally, was provided by Jazayeri and Shadlen (2010)
- Their experimental procedure was actually very similar to experiments in *Der Zeitsinn*

# Experimental procedure



# Data

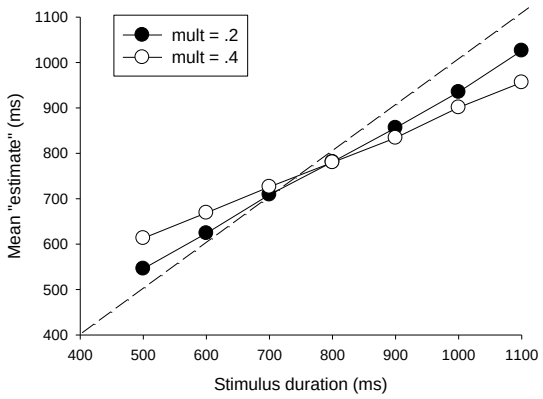

Production time (ms)
1,200
1,023
847
671
494
494
671
847
1,023
1,200
Sample Interval (ms)
Prior condition
Long
Intermediate
Short

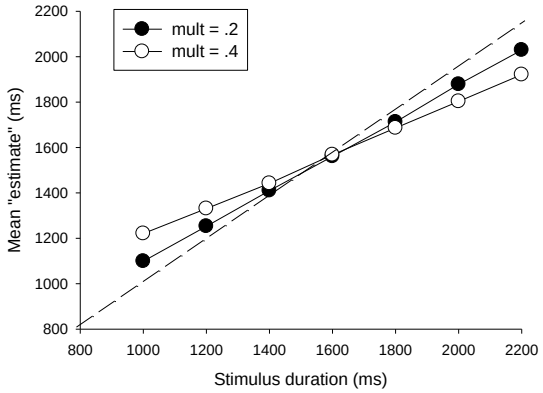
# Comments

- Vierordt's Law is obeyed for all the stimulus ranges used, but the indifference point clearly varies with the range of intervals used
- The basic representation of intervals was scalar (i.e. accurate mean and scalar variability) but the modelling of the data further assumed Bayesian decision rules, based on prior information about what the intervals in the range were

# ….continued

- Their Bayesian decision process actually takes account of the mean of all the intervals in the range, so it’s maybe not surprising that it predicts the general pattern of the results of their experiment well
- However, the one-back assimilation model can also produce output which looks like their data

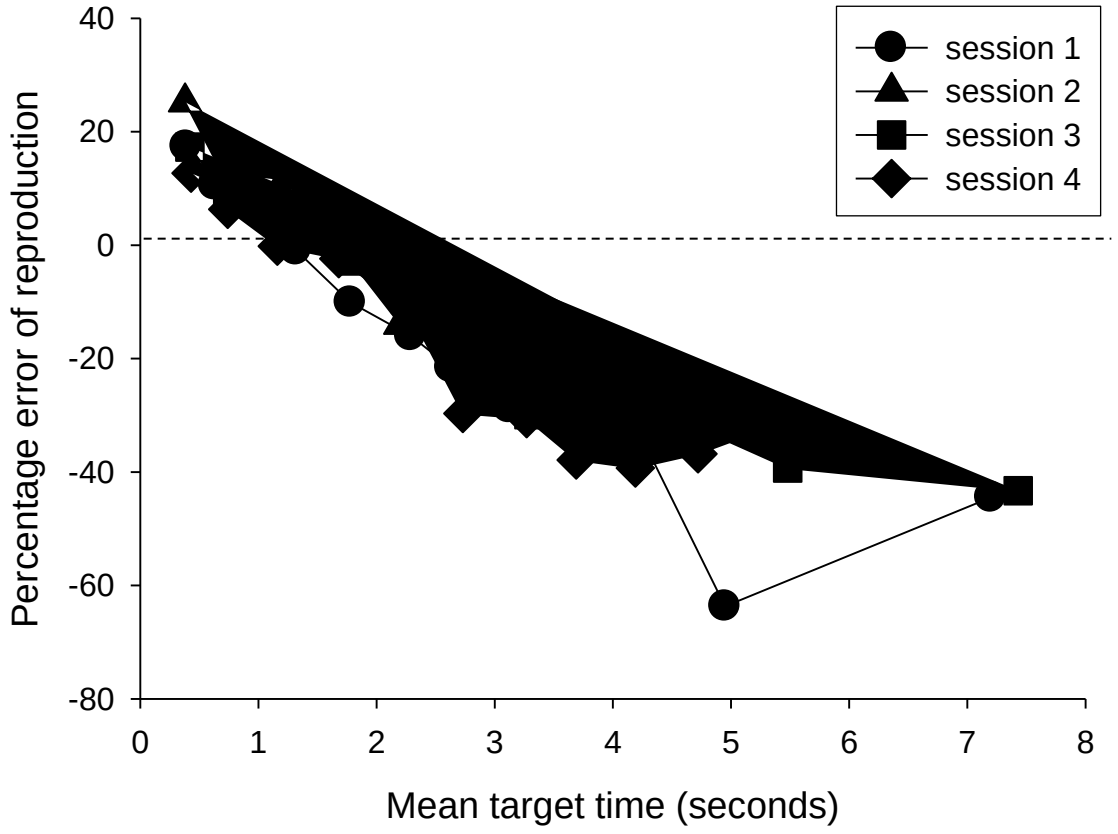

mult = .2
mult = .4
Mean "estimate" (ms)
Stimulus duration (ms)
1100
1000
900
800
700
600
500
400
400
500
600
700
800
900
1000
1100


mult = .2
mult = .4
Mean "estimate" (ms)
Stimulus duration (ms)
2200
2000
1800
1600
1400
1200
1000
800
800
1000
1200
1400
1600
1800
2000
2200

# General problem

- The indifference point often doesn't seem to be well-described by the mean of all the intervals, as we've seen: here's a reminder

# Data from Horing



# Furthermore….

- ….a model like this doesn't seem to be able to deal with the finding of Vierordt's Law in situations where individuals time a single interval…although Vierordt's Law isn't always obeyed in this situation (e.g. Woodrow, 1930)….
- Single interval timing poses a problem for all relativistic theories

# Potential conclusion

- A potential conclusion is that the Vierordt effects shown in different tasks don't actually have any common cause, and that different processes are responsible in the different cases
- Here, unusually, theoretical analysis seems to suggest that things that look the same aren't really the same at all, a kind of theoretical "disintegration" rather than the usual theoretical "integration" of different phenomena within the same theoretical framework

# Finally…

- You can see that this 19th. Century work, in spite of some peculiarities, not only produced reliable data, but also has posed some problems which are unsolved (and, it seems, quite difficult to solve) even today in the light of many recent advances in our understanding of time perception
- More generally, Vierordt seems to be a pioneer of experimental Psychology who is unjustly neglected….until now