Duration adaptation as a low-level, channel-based phenomenon

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Distortions of perceived time

Sub-second event duration
- Typically signalled by more than one sensory modality

- E.g.
  - Seen and heard speech components
  - Multiple speakers, multiple auditory and visual cues
  - Which ones belong together?
  - What happens when these cues are placed in conflict?
Distortions of perceived time

1. Multisensory integration of duration information
   - Concurrent presentation of discrepant visual and auditory durations
     - Asymmetric perceptual biases
     - Klink et al. (2011)
       - Audition biases vision but not vice versa
     - Chen and Yeh (2009)
       - Auditory oddballs expand visual duration but not vice versa (but see van Wassenhove et al., 2008)
2. Duration adaptation

- Repeated exposure to consistent duration information alters the perception of subsequent durations

Duration adaptation

These distortions are

- 1. Sensory specific
  - No transfer to the non-adapted modality

- 2. Bandwidth-limited around the adapted duration

Consistent with a channel-based account of duration perception\(^1\).

Processing hierarchy?

Should these illusions be described as mandatory or cognitive?

Low-level phenomena?

DA (duration adaptation) and MSI (multisensory integration) induced duration illusions

– Generated by separate mechanisms?
– Distinct processing stages?
– A neural hierarchy for illusions of time?
Hypotheses

- Is it possible to adapt to an duration induced by multisensory integration?
- If duration aftereffects and MSI-based distortions arise from separate mechanisms….
  - interdependency between illusions will be unidirectional
## Hypotheses

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- **Auditory**
- **Visual**
- **Early MSI, late DA**
- **Early DA, late MSI**
Experiment 1 – Mapping out MSI-based duration distortions

– Which A and V combinations promote maximal duration distortions?

– Cue combination experiment
MSI experiment

Bimodal test

320ms

180-570ms

(distracter)

(distracter)

Unimodal reference

220-440ms

Time

Auditory

Visual
MSI experiment

Visual stimuli
- Gaussian blob of white light (SD $\sigma = 2.1^\circ$, peak luminance 94 cd/m$^2$ against a grey background of luminance 47 cd/m$^2$)
- Presented via CRT

Auditory stimuli
- Burst of white noise of peak intensity 75dB
- Presented via headphones

Uniform temporal profiles.

Physical durations and onset-offsets times:
- verified via simultaneous capture on a dual-channel oscilloscope
MSI experiment

Procedures

- 320ms test, variable reference centred on 320ms.
- Test coupled with concurrently presented ‘distracter durations’ (180-570ms) from opposite modality
- 2AFC unimodal duration discrimination judgments
  - ‘which was longer, 1st or second visual/auditory duration?’
  - ‘Try to ignore the stimulus from the opposite modality’
MSI experiment

Bimodal test
- 320ms
- (distracter)
- 180-570ms
- (distracter)

Unimodal reference
- 220-440ms

Time

Auditory  Visual
MSI experiment

For each modality combination:

- 11 distracter durations
- 7 reference durations
- 10 repetitions per condition per block
- Minimum of 3 blocks per subject (n=7)

- Min. 30 repetitions per condition
- Min. 4620 trials per observer
MSI experiment

Visual test, auditory distracter

Auditory test, visual distracter

PSE = 256ms
PSE = 341ms
PSE = 304ms
PSE = 317ms
MSI experiment

Visual test, auditory distracter

Auditory test, visual distracter
MSI experiment

PSE (ms)

Distractor Duration

Visual test, auditory distracter
Auditory test, visual distracter

(n=7)
MSI results

Mechanism underlying effects?

Sound ↑ perceived visual duration by accelerating visual pacemaker’s pulse rate (Chen & Yeh, 2009; Penton-Voak et al., 1996; Wearden et al., 1998).

Fails to explain ↓ perceived visual duration when V=320ms, A<320ms.....
MSI results

Mechanism underlying effects?

Klink et al (2011) offer explanation based on multi-stage interaction between
- Perceptual grouping
- Temporal ventriloquism
- Auditory influence on V, A (and AV?) pacemaker rates
MSI results

- Is there a more parsimonious explanation?

- Perhaps MSI of duration information shares commonality with interactions between temporal rate (Roach et al., 2006) or visuo-haptic size (Ernst & Banks, 2002)?
  - Integration reflects relative sensory reliabilities and probability of a common cause?
MSI – modelling results

Effects modelled using a Bayesian approach

– Based on model proposed for multisensory conflict between auditory and visual temporal rate (for details see Roach et al., 2006).

MSI – modelling results

Effects modelled using a Bayesian approach

- Gaussian likelihood function centred on the physical duration of the (non-distracter) stimulus
- Likelihood function’s spread corresponds to the uncertainty (unimodal duration discrimination threshold) of that estimate.
MSI – modelling results

- Effects modelled using a Bayesian approach
  - likelihood function is combined with a prior
    - Reflects accumulated knowledge of the correspondence (i.e. joint statistics) of encountered visual and auditory durations
  - according to Bayes’ rule
    - Posterior arises from the product of likelihood and prior
Modelling visual judgments

Visual likelihood centred on 320
σ = 0.0672 log units
Prior centred on 400ms

Visual likelihood centred on 320
σ = 0.0672 log units
Prior centred on 800ms
Modelling auditory judgments

Auditory likelihood centred on 320
σ = 0.026 log units
Prior centred on 400 ms

Auditory likelihood centred on 320
σ = 0.026 log units
Prior centred on 800 ms
Model output

- Best fitting values for width of prior = 0.076 log units
- Best fitting values from prior pedestal = 0.1

Difference between outputs arises solely from the width of their respective likelihood functions
MSI – modelling results

With two free parameters, model output provides an excellent fit to the data.

Although other pacemaker-based explanations remain a possibility…

Model outputs suggest MSI duration effects share commonalities with many other cue-combination phenomena.
Adaptation vs Multisensory integration

- Sensory integration produces marked distortions of visual duration
- Opportunity to probe processing hierarchy of duration processing
  - Use MSI mechanisms to generate maximal distortions of perceived visual duration
  - MSI-based distortions available to duration adaptation mechanisms?
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- **Red**: Auditory
- **Blue**: Visual
- **Gray**: Early MSI, late DA
- **Gray**: Early DA, late MSI
Duration adaptation vs Multisensory Integration

32
Duration adaptation vs Multisensory Integration

100 adaptation presentations followed by 4 top-up test cycle.
Duration adaptation

Mean Reproduced Duration $\text{MRD} = \text{average of 90 reproductions of 320 p/condition, p/observer (n=7)}$.

$\text{MRD}$ gives measure of Aftereffect Magnitude (AM)

$$\text{AM} = [\text{MRD}_{\text{Auditory200ms}}] - [\text{MRD}_{\text{Auditory510ms}}]$$

Thus, positive values indicate repulsive or rebound type aftereffects.
Duration adaptation

Two conditions compared:

- *Perceived* difference between visual adapting and visual test stimuli

- Duration matched *Physical* difference between visual adapting and visual test stimuli

- If MSI precedes DA, aftereffects should be similar for both conditions
Physical vs *perceptual* adapt-test duration differences

Physical

- Auditory
- Visual

Perceived

- Auditory
- Visual

Adaptation phase

- 269ms or 375ms
- 200ms or 510ms

Test phase

- Reproduce the duration
- 320ms

269ms or 375ms

Physical

- Auditory
- Visual
Physical vs perceptual adapt-test duration differences
Duration adaptation vs. Multisensory integration

- Physical adapt-test duration differences produce repulsive duration aftereffects in line with previous findings\(^1\)

- …duration-matched MSI-induced distortions are unable to activate duration adaptation mechanisms

- Data suggestive of a processing hierarchy where DA mechanisms operate at an earlier processing stage than the integration of temporal information across the senses?

DA precedes MSI?

- MSI-induced duration distortions are not available to DA mechanisms
- Further prediction of the ‘early DA’ hypothesis:
  - Adaptation-induced distortions will feed-forward to influence (later stage) multisensory integration
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Multisensory integration with prior auditory adaptation

Adaptation phase

Test phase

Which was longer?

V & A = 320ms

200-440ms

160ms or 640ms
Multisensory integration with prior auditory adaptation

Adaptation phase: unimodal adaptation
- Adapting and top-up stimuli: auditory durations of 160ms or 640ms

Test phase: Bimodal test, unimodal reference
- 320ms A&V test
- Variable (200-440ms) visual reference

Identical adapt/top-up/test design to previous experiment
Multisensory integration with prior auditory adaptation

**Adaptation phase**
- 160ms or 640ms

**Test phase**
- Which was longer?
- V & A = 320ms
- 200-440ms
Multisensory integration with prior auditory adaptation

Mean PSE shift = 29ms (SE = 7ms)
Multisensory integration with prior auditory adaptation

- Clear adaptation-induced modulation of visual duration perception

- Lateral separation between psychometric functions = ‘PSE shift’
  - PSE shift = 29ms (averaged across observers)
Implications....

Transfer of duration aftereffects to influence subsequent multisensory integration

- serial interaction between DA and MSI mechanisms
- Duration adaptation is completed prior to the nervous system combining temporal information across the senses
What does this tell us?

- Duration perception is a highly flexible process
- Modified via the twin mechanisms of sensory integration and temporal adaptation
What does this tell us?

- Superficially, these mechanisms produce similar distortions of temporal perception.

- Our findings reveal a clear separation in their processing order:

- The nervous system incorporates recent sensory history prior to combining sensory inputs across sensory channels.
Thanks for listening