The index of cognitive activity (ICA) –

a promising objective measure of Cognitive Load when learning with different visualization formats

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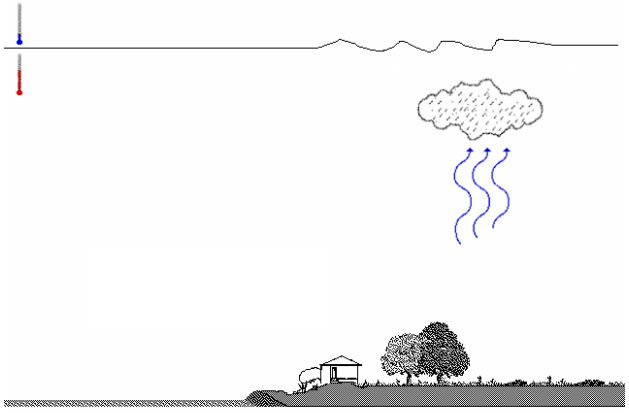
Learning with Multimedia (Mayer, 2014)

Multimedia Principle:

Text + Visualization



As the air in this updraft cools, water vapor condenses into water droplets and forms a cloud.

>

Text

As the air in this updraft cools, water vapor condenses into water droplets and forms a cloud.

Learning with Animation vs. Static Picture

Research:

- inconsistent (Tversky, Bauer-Morrison, & Bétrancourt, 2002; Höffler & Leutner, 2007)

→ „What is better?“ → global question is not fruitful

- differentiated approach:

→ for whom, under which conditions and why?

➔ focus on processing demands of learners when learning with animations or static pictures

Characteristics of animations

- possible disadvantages:
  „Overwhelming“
  - transience (e.g., Ayres & Paas, 2007; Castro-Alonso, Ayres, & Paas, 2015)
    - information can be missed
    - learners have to memorize different phases/states

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  - visual complexity (Lowe, 2004)
    - intra-split-attention
    - relevance vs. salience

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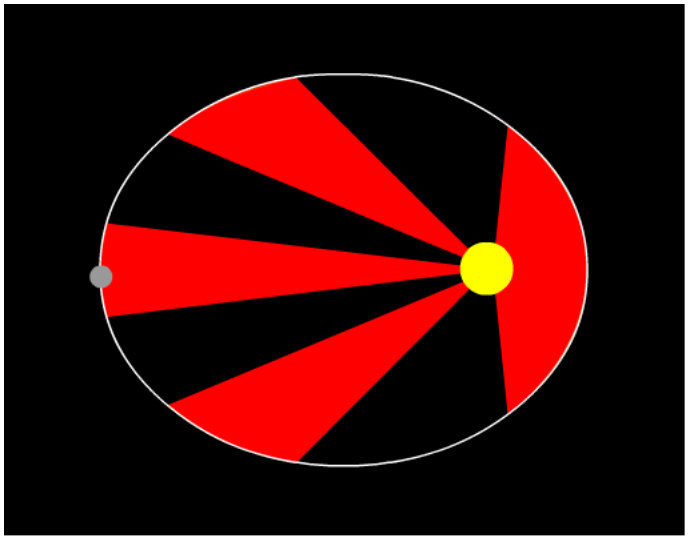
    - learners have to memorize different phases/states
  - visual complexity (Lowe, 2004)
    - intra-split-attention
    - relevance vs. salience
- possible advantage:
  - mental animation of dynamic information (e.g., Hegarty, 2004; Lowe, 2003)

Animation vs. Static Picture

- essential difference: presentation of dynamic information

- learning with static pictures: dynamic information has to be

  1.) inferred by the learner
  2.) mentioned in an external source (text)

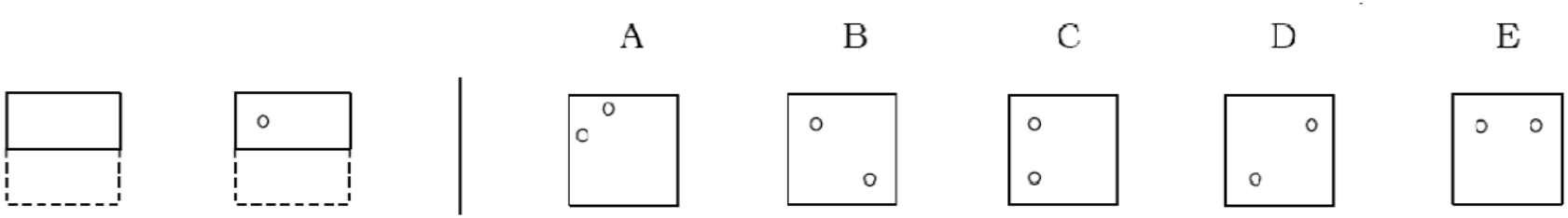


Animation vs. Static Picture

- who profits from dynamic information presented in animations?

→ learners with problems in mentally animating this dynamic information (=> low spatial abilities?)

→ „Ability-as-compensator“- Hypothesis (e.g., Höffler, 2010, Höffler & Leutner, 2011)



(Ekstrom, French, Harman, & Dermen, 1976)

Measuring Cognitive Load

- subjective ratings (e.g., Paas, 1992)
- dual task paradigms (e.g., Brünken, Steinbacher, Plass, & Leutner, 2002)
- physiological measurements (e.g., Just et al., 1996)
  - heart rate
  - positron emission tomography (PET)
  - electroencephalography (EEG)
  - electrodermal activity (EDA)
  - pupil dilation measurements
    - task-evoked pupillary responses (TEPRs) (e.g, Van Gerven, Paas, van Merriënboer, & Schmidt, 2004)
    - index of cognitive activity (ICA) (e.g., Marshall, 2002; Bartels & Marshall, 2012)

Hypotheses / Research Questions

- Multimedia Principle: Text and visualization should be better suited than text-only (control group)

- Learning with animation vs. static picture:
  - animations should be better suited than static pictures, particularly if the information about the dynamic features is not given in the text

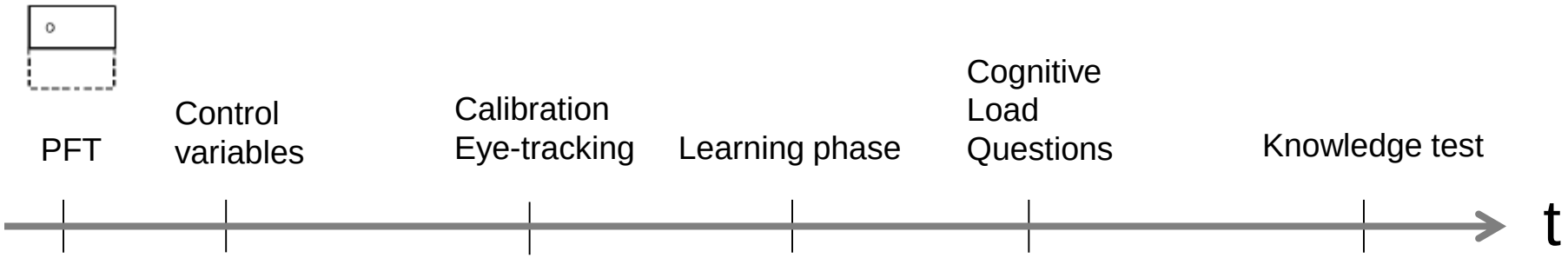
  - ability-as-compensator: learning with animation should be better suited for learners with low spatial abilities (not necessarily for learners with high spatial abilities)

  - explorative: How to best measure Cognitive Load: Is cognitive activity mirrored by pupil changes (ICA)?

Methods

2x3-Design (*N* = 198)

	Animation	Static Picture	Text-only	Total
Text **with** dynamic information	32	34	32	98
Text **without** dynamic information	34	32	34	100



Planets are orbiting the sun on an ellipse, not on a circle. At this, the sun is not centered in the middle of the ellipse.

Kepler‘s second law states that the line joining a planet and the sun sweeps out equal areas during equal intervals of time.

Text **without** dynamic information

Text **with** dynamic information

When the distance between sun and planet is getting shorter, a planet has to travel a greater distance so that the line joining a planet and the sun sweeps out equal intervals of time. Therefore, to coincide with Kepler‘s second law, a planet has to move faster, the shorter ist distance is to the sun, and to move slower, the larger ist distance is to the sun.

Cognitive Load Items

- 7-point Likert scale
  - 1 (not at all) to 7 (very much)

1) How much mental effort did you invest?
2) How difficult was it to learn with the material?
3) How much did you concentrate during learning?
4) How demanding was the task for you?

(Paas, 1992; Cierniak, Scheiter, & Gerjets, 2009)

Index of cognitive activity (ICA)

- Marshall, 2002; Bartels & Marshall, 2012
  - based on changes in pupil dilation during learning phase
  - uses signal processing techniques of wavelet analyses
  - is computed for each second of a task
  - values between 0 and 1values
  - needs to be standardized for each participant
  - was divided in
    - ICA-Visualization (ICA-value for watching the visualization)
    - ICA-Text (ICA-value for reading the text)

Knowledge test

- example of verbal factual knowledge
  - *“Please write down everything you can remember from the previous learning phase.”*

- example of transfer knowledge
  - *“Consider, the second law of Kepler would be true: What is the effect on the course on the planet’s speed when the sun is closer to the center (but not in the center)?”*

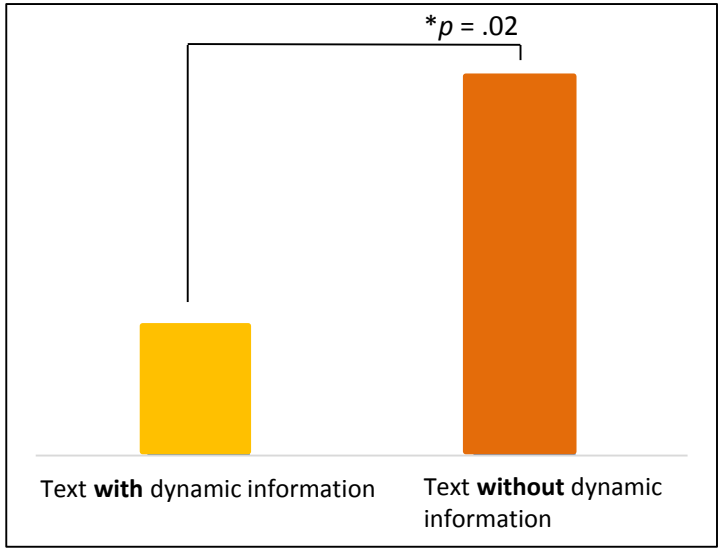
Results – Cognitive Load

- influence of **text format**
  - difficulty, effort, concentration, demand: $F_s < 1.48$, $p_s > .23$
- influence of **visualization format**
  - effort, concentration, demand: $F_s < 2.18$, $p_s > .12$
  - difficulty: $F(1, 185) = 2.76$, $p = .066$, $\eta^2_p = .029$
    - text only > animation = static picture
- interaction **text information*visualization format**
  - $F_s < 1.19$, $p_s > .31$

Results – ICA for text area

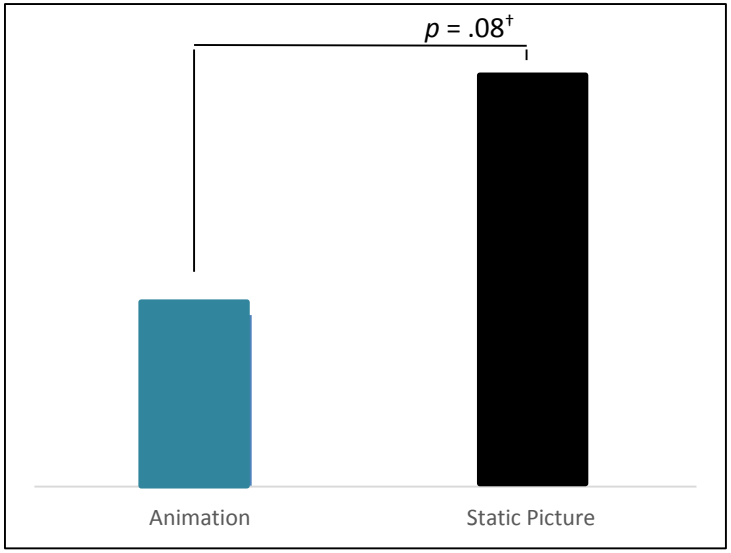
N = 115

Text format



- main effect (text format): **with** < **without** dynamic information
  - $F(1, 111) = 5.99$, $p = .02$, $\eta^2_p = .05$

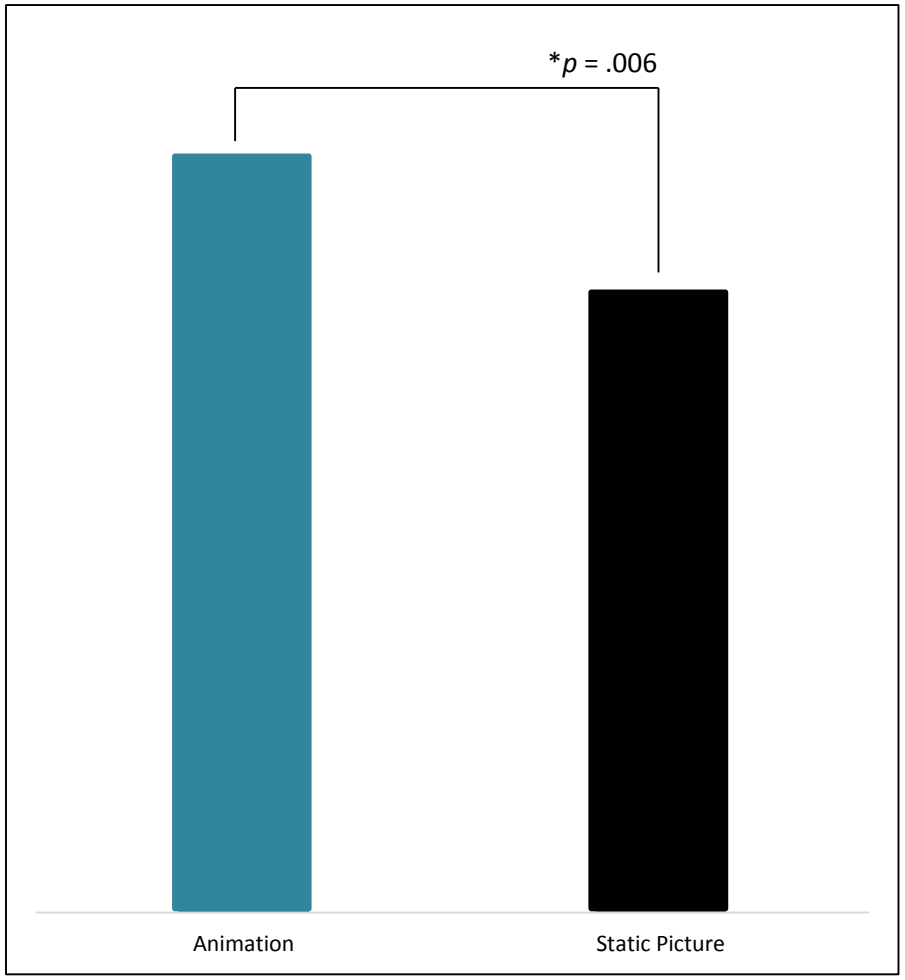
Visualization format



- main effect (visualization format): **animation < static picture**
  - ($F(1, 111) = 3.17$, $p = .08^{\dagger}$, $\eta^2_p = .03$)
- no interaction:
  - ($F(1, 111) = 1.53$, $p = .22$, $\eta^2_p = .01$)

Results – ICA for visualization area

N = 115

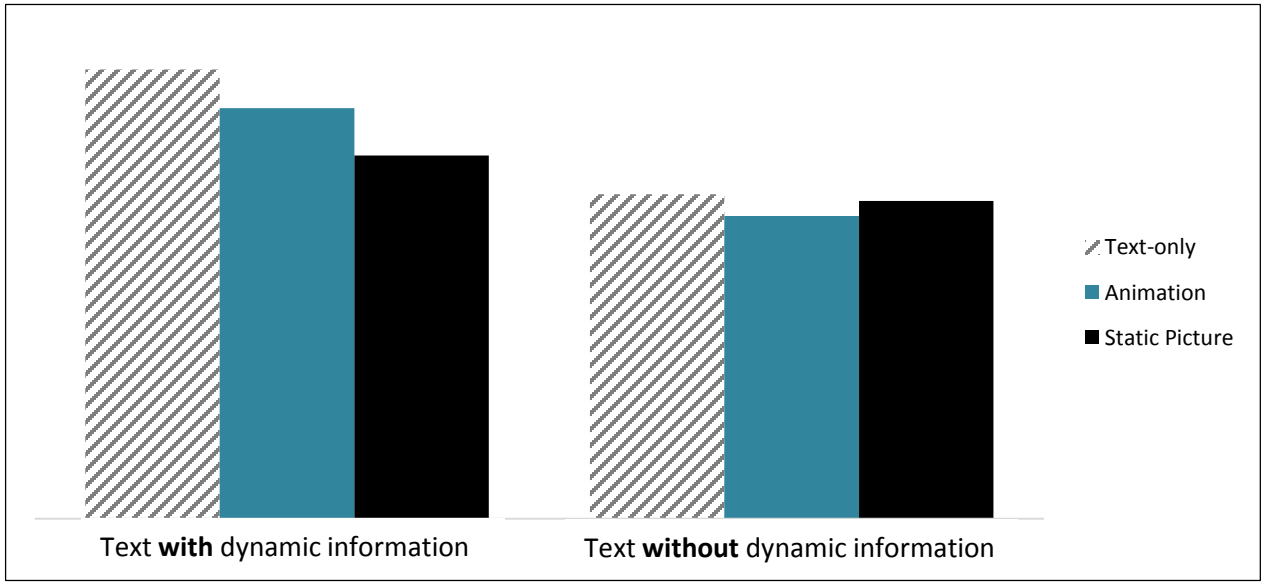


- main effect (visualization format): **animation** > **static picture**
  - $F(1, 111) = 7.89$, $p = .006$, $\eta^2_p = .07$
- no main effect (text format):
  - $F(1, 111) = 0.01$, $p = .92$, $\eta^2_p = .00$
- no interaction:
  - $F(1, 111) = 1.35$, $p = .25$, $\eta^2_p = .01$

Results – Learning outcome (Retention)

N = 198

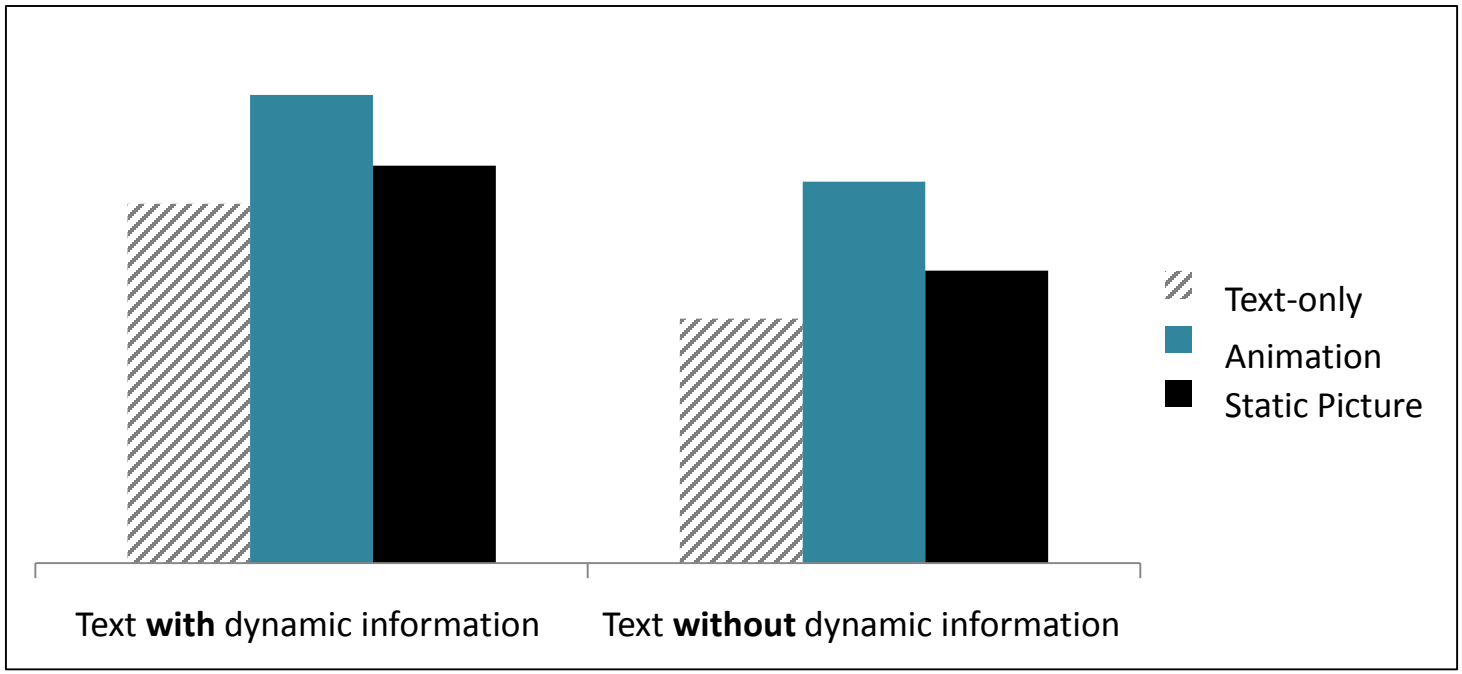
- main effect (text format): $F(1, 192) = 20.27$, $p < .001$, $\eta^2_p = 1.00$
  - **with** > **without** dynamic information
- no main effect (visualization format): $F(1, 192) = 1.77$, $p = .17$, $\eta^2_p = .02$
- no interaction: text does not compensate informational disadvantage of static picture; $F(1, 192) = 1.41$, $p = .25$, $\eta^2_p = .01$



Results – Learning outcome (Transfer)

N = 198

- main effect (text format): $F(1, 192) = 14.71$, $p < .001$, $\eta^2_p = .07$
  - **with** > **without** dynamic information
- main effect (visualization format): $F(1, 192) = 6.12$, $p = .003$, $\eta^2_p = .06$
  - **animation** > **static picture** > **text-only**
- no interaction: text does not compensate informational disadvantage of static picture; $F(1, 192) = 0.51$, $p = .60$, $\eta^2_p = .01$



Results – Learning outcome (Transfer)
PFT- Ability as compensator

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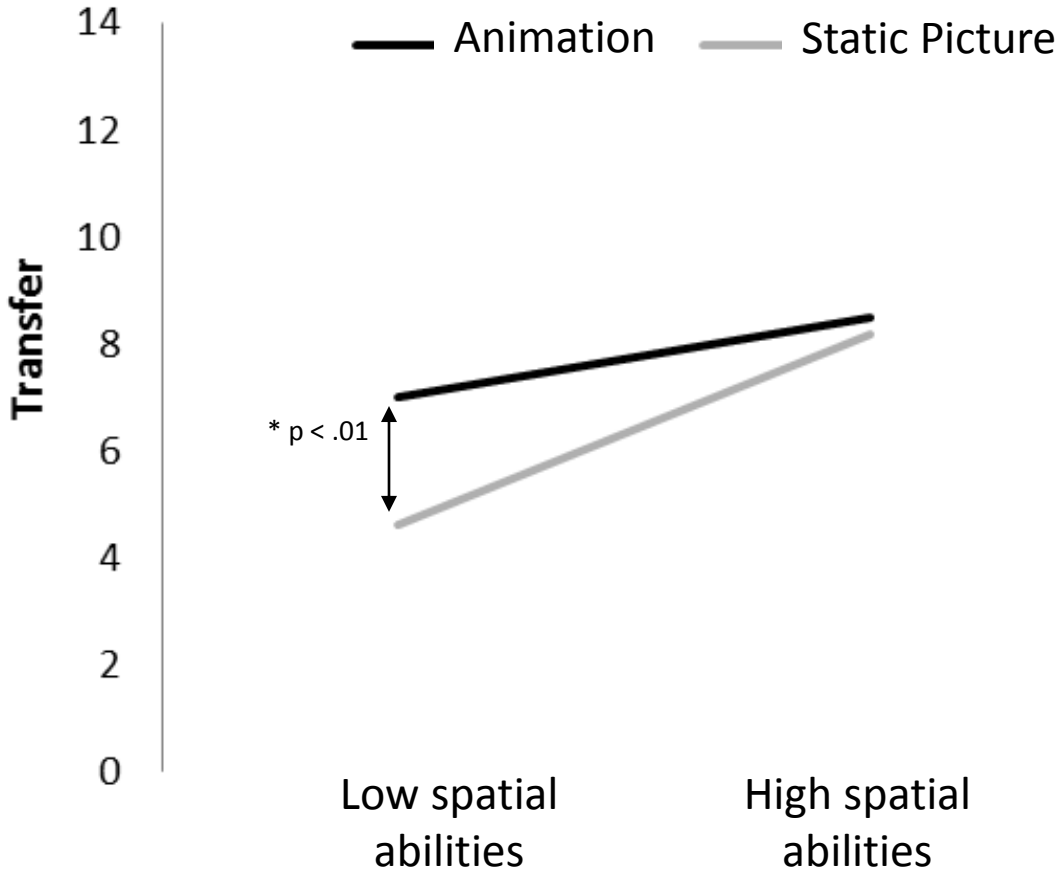
N = 115

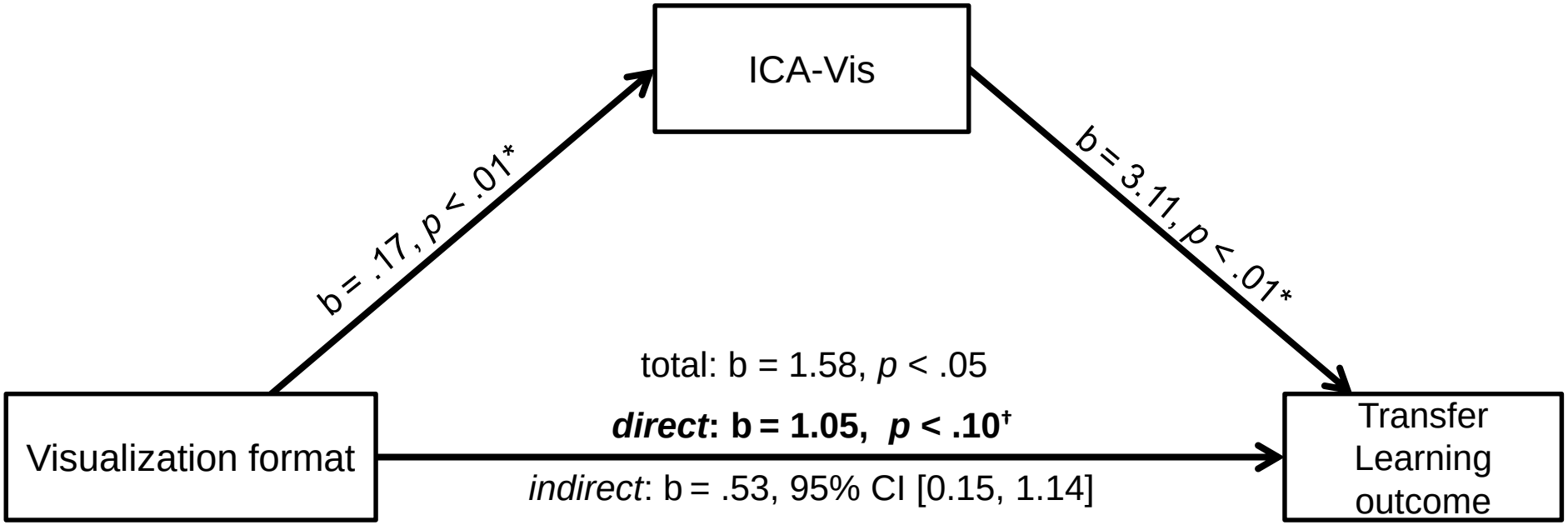


Results – ICA (Transfer)

N = 115

- ICA regarding visualization: animation > static picture

Mediation analysis:



→ **Mediation: indirect effect for ICA-Vis**

Summary of Results

Enhanced learning outcomes when learning with an animation compared to a static picture,

- irrespective of whether dynamic information in the text is given or not
- especially for learners with low spatial abilities (ability-as-compensator)

Enhanced learning outcomes when learning with animations can (partially) be explained by pupil dilations (= ICA)

- ICA = able to detect differences
  - 2 different scores
    - visualization format: **animation** > **static picture**
    - text format: text **without** > text **with** dynamic information

Discussion

- Measurement of CL
  - subjective ratings ≠ able to detect differences
    - no differences between visualization and text format
    - splitting between visualization and text format?
  - ICA = more able to detect differences
    - text **without** dynamic information = higher workload; however text **with** dynamic information is more supportive regarding transfer knowledge test → blackbox?!

- Results showed that high "active processing" when learning with visualization is supportive for learning outcome
  - how can we optimize this process?
    - prompting learners to actively engage in learning material (= inferences?)

Thank you very much for your attention and interest!

For more critical comments, remarks and/or hints:

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