Sensory responsivity and its connection to sympathetic activation/deactivation

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Introduction

This study introduces sensory responsivity (SR) which describe individual differences in response strength to sensory stimuli and is hypothesised to affect stress responses in students and, in turn, their learning. The first part of the study developed a measure to assess the trait of sensory responsivity by using multidimensional item response theory. The lab experiment in the second study investigated the connection between sensory responsivity and sympathetic activation in relaxation tasks and concentration tasks. Because the lab experiment took place in a very quiet lab, where sensory input was generally low, the classroom experiment in study three investigated sympathetic activation for learning tasks in a naturalistic setting with varying levels of sensory input.

Participants

Study one				Study two				Study three			
N	Female	Male	Age (y)	N	Female	Male	Age (y)	N	Female	Male	Age (y)
535	244	258	10 - 16	100	59	39	12 - 21	35	19	16	17 - 18

Methods – research design & analysis

The study was approved by the south-east Regional Ethics Committee (REK) and the Norwegian Centre for Research Data (SIKT) and students (and their guardians if they were below 16 years) provided informed consent for participation.

Study one: Scale development

All students were anonymously surveyed in whole school classes while supervised by their teacher. All items were mandatory, so that there was no missing data. The data set was analysed by multidimensional item response theory (logistic regression/Rasch modelling). R version 4.3.1 (R Core Team, 2023) with R studio version 2023.12.1 was used for the statistical analysis for all three studies, and I estimated the IRT models with the R package mirt (Chalmers, 2012).

Figure 1. The lab setup.

Study two: Lab experiment

Students performed two cognitively demanding tasks (i.e., watching an instructional video with pre-/post-tests, and a 2-back test) and two relaxation tasks (i.e., watching a relaxing nature video, and 14 minutes of hearing clicks with eyes closed in the sensory gating paradigm).

We collected skin conductance (SC) and EEG data with a Brainproducts ActiChamp Plus system and a BIP2AUX SC sensor at 5000 Hz with a sensory gating paradigm (90 dB paired clicking sound randomly given at 8 ± 2 seconds with 500 ms between the paired clicks) with eyes closed to avoid blinking artefacts. Online reference was one ear lobe electrode, offline reference was the mean of both ear lobe electrodes. The Cz electrode was used in the sensory gating analysis which was performed with the Analyzer 2 software, mainly following the steps of Zabelina and colleagues (2015). SC data was down sampled to 10 Hz prior to analysis as the fastest-varying part of the signal is centred around 1 Hz. MATLAB Ledalab was used for decomposition of the tonic (slow-varying) and phasic (fast-varying) components of the activity of the sympathetic nervous system using the continuous decomposition analysis method (Benedek & Kaernbach, 2010). For all four tasks a median split was performed for each SR scale factor (SR1 and SR2), and group SC differences were assessed. Moreover, a multiple regression analysis with both SR factors and sensory gating variables as input variables and phasic SC activity as the outcome variable was performed.

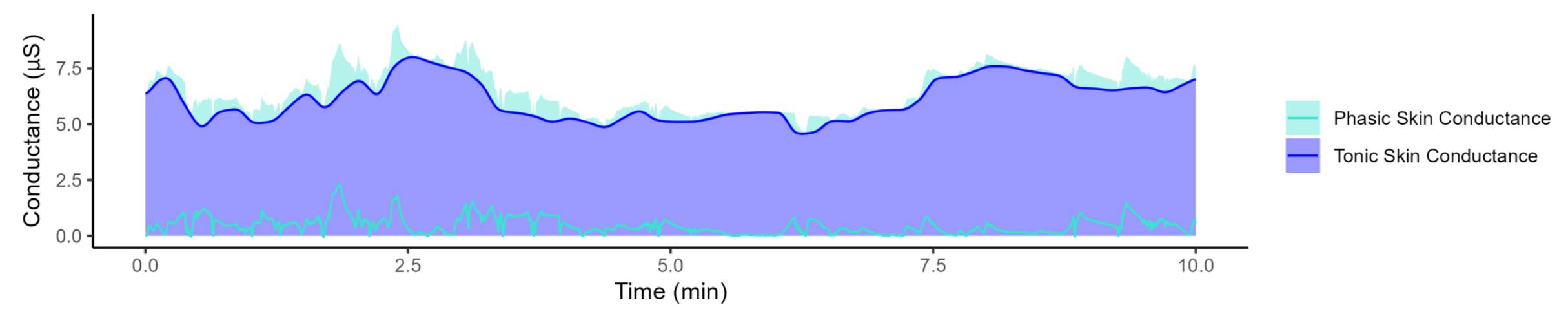


Figure 2. An example of the SC signal and its two components.

Study three: Classroom experiment

Two upper secondary school physics classes participated in an instructional activity intervention where one class were first given activities with less intense sensory stimuli and the next time, they were given the same instructional activities only with more intense sensory stimuli. The other class received the same intervention, only in the reverse order. The order of the themes the students worked with was kept the same for both groups in such a way that both groups had theme one the first time and theme two the second time, see Figure 3. Both lessons consisted of a lecture with class interaction (25 min - students could take notes on laptop vs. by hand), worked examples at the blackboard (10 min - students could not take notes vs. taking notes by hand), working with tasks with four different difficulty levels (20 min - using laptop with digital book vs. by hand with printed book), a quiz (10 min - Kahoot! vs. sitting on their desks and showing answers with their arms), and a round of the Alias game with appropriate content (10 min - Explaining concepts orally vs. explaining orally and drawing).

We collected SC data with the validated BITalino EDA system (Batista et al., 2019) at 10 Hz and analysed the data as in study two. The lessons were videotaped to synchronise activities to SC measurements. The survey data was collected at school with the teachers and researcher present. A regression analysis with each of the two SR factors was performed for the two conditions of less/more intense sensory stimuli vs. tonic and phasic SC activity, respectively.

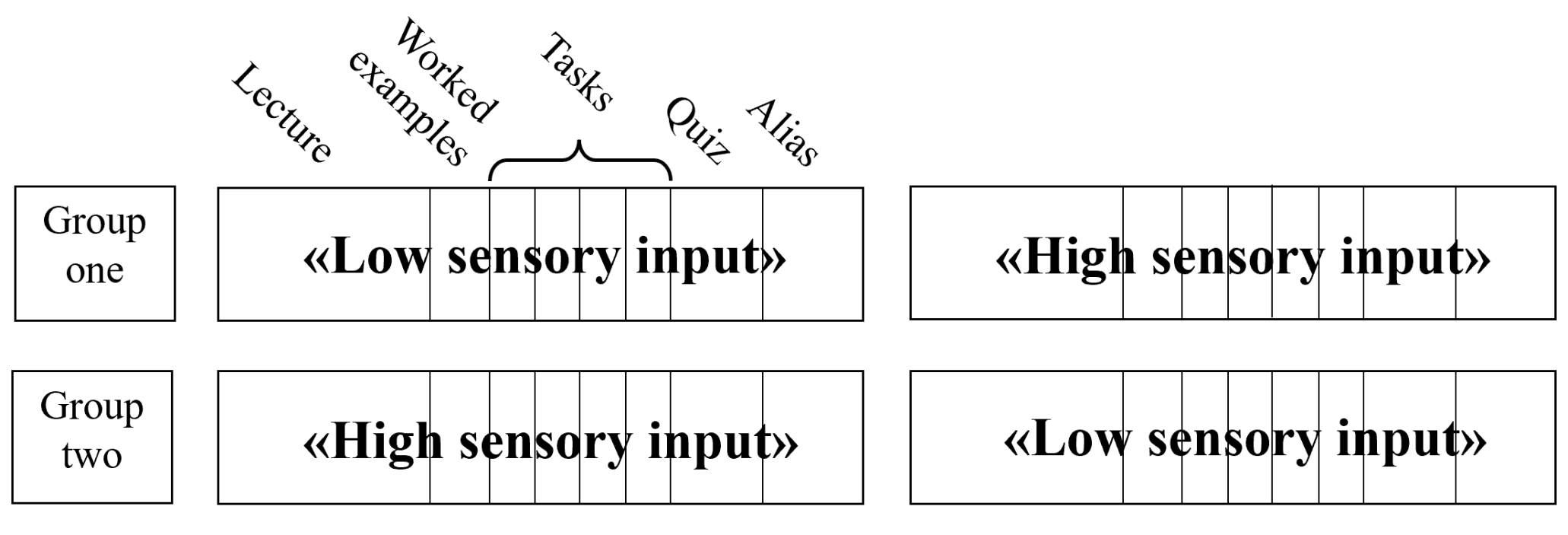
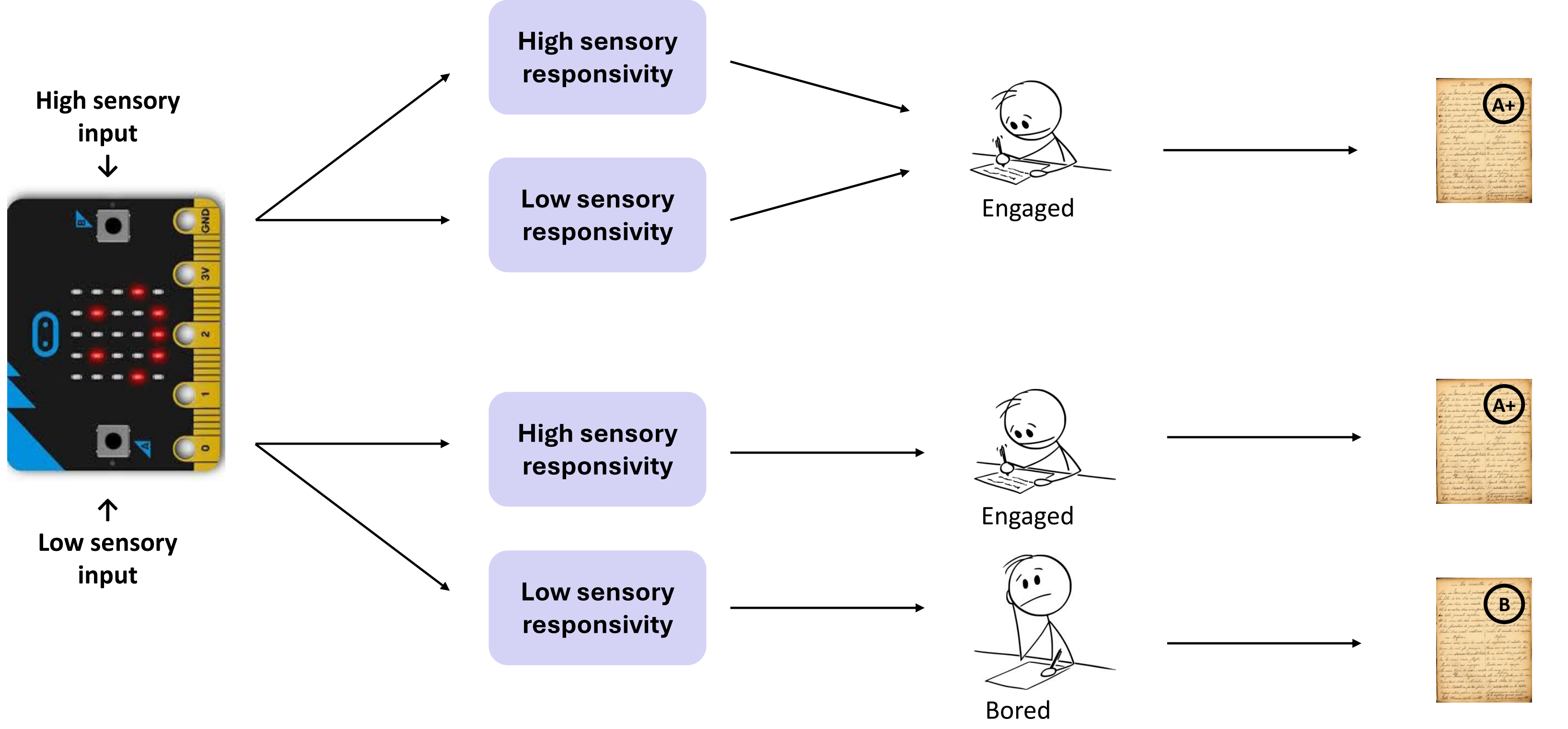


Figure 3. An overview of the experimental design.

Summary and implications for classroom learning



Results – scale development

The Sensory Responsivity Scale (SR scale)

- 27 items
- 3 level Likert scale – scored 0, 1, and 2

Classical test theory (Internal validity and structure)

- No items below .3 item-total correlation
- M = 28.2, SD = 7.69
- Cronbach's alpha = .90

Exploratory sample (Dimensionality assessment)

- Graded response model (GRM)
- Tested 1 – 5 dimensions (factors)
- Bayesian Information Criteria (BIC) lowest for 2 dimensions

Confirmatory sample (Item fit and model fit)

- RMSEA = .062 (90 % CI = [.054, .069])
- SRMR = .067
- Good fit for all items based on the S-χ^2 test

Correlations (Construct validity)

- School disengagement behaviour .28-.30, $p < 10^{-10}$
- Sensory processing sensitivity .30-.45, $p < 10^{-6}$
- Factor correlation SR1 and SR2 .56

The sensory responsivity scale

SR1 – Exteroception

1. I often think that the movie theatre sound is too loud.
2. Flashing lights are very annoying.
3. It is very uncomfortable to hear sirens close by.
4. I can't eat bitter foods, such as grapefruit and Brussels sprouts.
5. It often becomes too noisy in the classroom for me.
6. I am good at hearing the smallest of sounds.
7. I think that some people breathe noisily.
8. I prefer to move carefully.
9. I notice strange tastes more often than others.
10. It is very uncomfortable to be surrounded by clutter.
11. It is very important to me that it is neither too bright nor too dark in a room.
12. When I enter a room, I immediately notice bright lights.
13. It is difficult for me when others eat food with an unpleasant smell.
14. Labels in clothes are often annoying.
15. I'm so ticklish that it almost hurts when somebody tickles me.
16. I often notice smells that other people don't.
17. There are many foods I don't like to eat.
18. I am more often cold than other people.

SR2 – Interoception

19. My shoes must be very comfortable.
20. It is unpleasant to stand for a long time.
21. There are types of clothes or fabrics that feel unpleasant to wear.
22. I only wear comfortable clothes.
23. I quickly notice when my muscles get tired.
24. To have a comfortable place to sit is important to me.
25. I react strongly to being hungry.
26. I notice more easily than others that my body feels tired.
27. I function much poorer than usual when I am tired.

Results – lab & classroom experiments

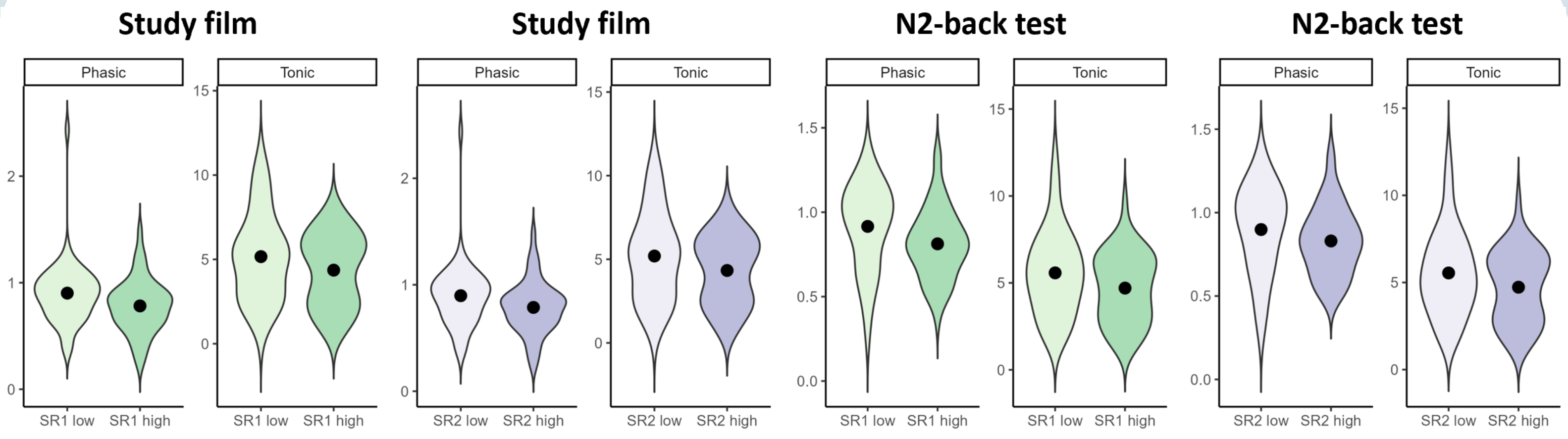


Figure 4a. Because of non-normality of the data sets, all group comparisons were done with the Wilcoxon signed rank test with continuity correction. All group differences were significant at a p<2.2e-16 level, and the Wilcoxon effect sizes ranged from .15 to .28 where the largest effect sizes belonged to the phasic component. For both cognitively demanding activities (i.e., the study film and the N2-back test), all groups with high sensory responsivity (by either SR1 or SR2), demonstrated lower phasic and tonic skin conductance levels. Because the phasic variable correlates negatively with learning (Flø & Flø, in preparation), this indicates a learning benefit for high sensory responsivity students in quiet environments (i.e., the lab).

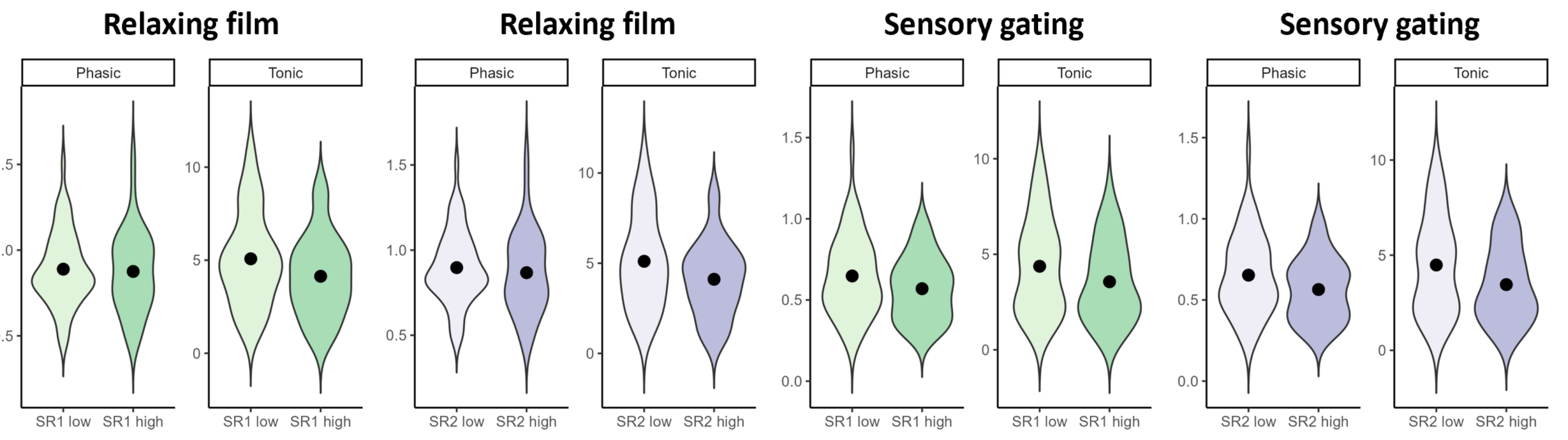


Figure 4b. Because of non-normality of the data sets, all group comparisons were done with the Wilcoxon signed rank test with continuity correction. All group differences were significant at a p<2.2e-16 level, and the Wilcoxon effect sizes ranged from .04 to .27. For both relaxing activities (i.e., the relaxing film and the sensory gating paradigm with eyes closed), all groups with high sensory responsivity (by either SR1 or SR2), demonstrated lower phasic and tonic skin conductance levels. The largest effect sizes belonged to the tonic component, indicating that in relaxation activities in a quiet lab environment, high sensory responsivity students are more relaxed than the low sensory responsivity students.

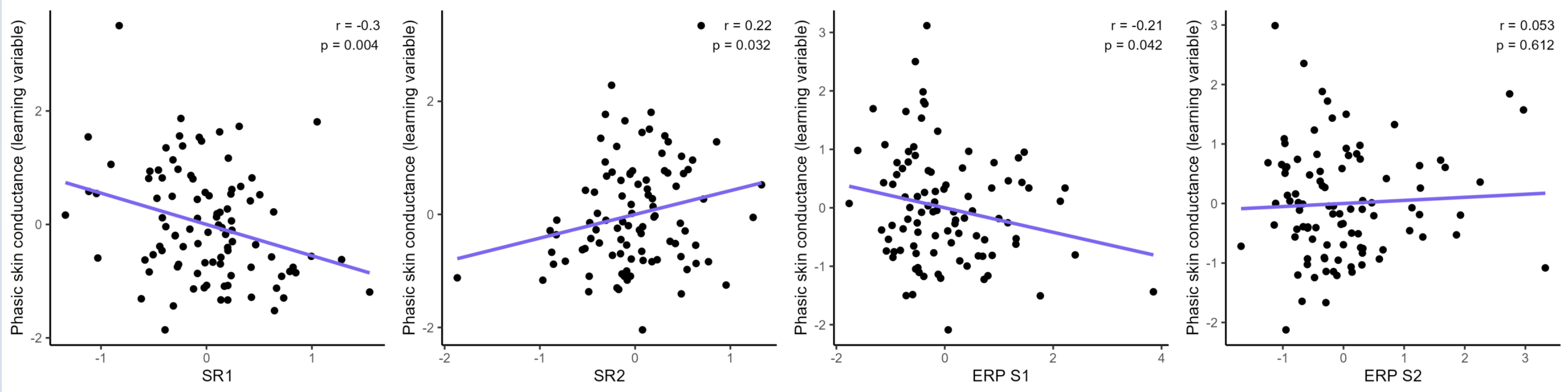


Figure 5. The multiple regression with the phasic variable (which correlates negatively with learning Flø & Flø (in preparation)) as outcome demonstrated that the first factor of the sensory responsivity scale, the SR1 variable correlated negatively with the phasic variable, indicating that high SR1 values are beneficial for learning in a quiet environment. On the other hand, the SR2 variable correlates positively with the phasic variable, indicating that high SR2 values are disadvantageous for learning in a quiet environment. The amplitude of the first P50 signal (ERP S1) in the sensory gating paradigm also correlated negatively with the phasic variable, indicating that large amplitudes of the preconscious auditory sensory input signal are beneficial for learning in the lab environment. The amplitude of the second P50 signal (ERP S2) was not significant. Sensory gating was not significant, thus we chose to rather include the separate amplitudes.

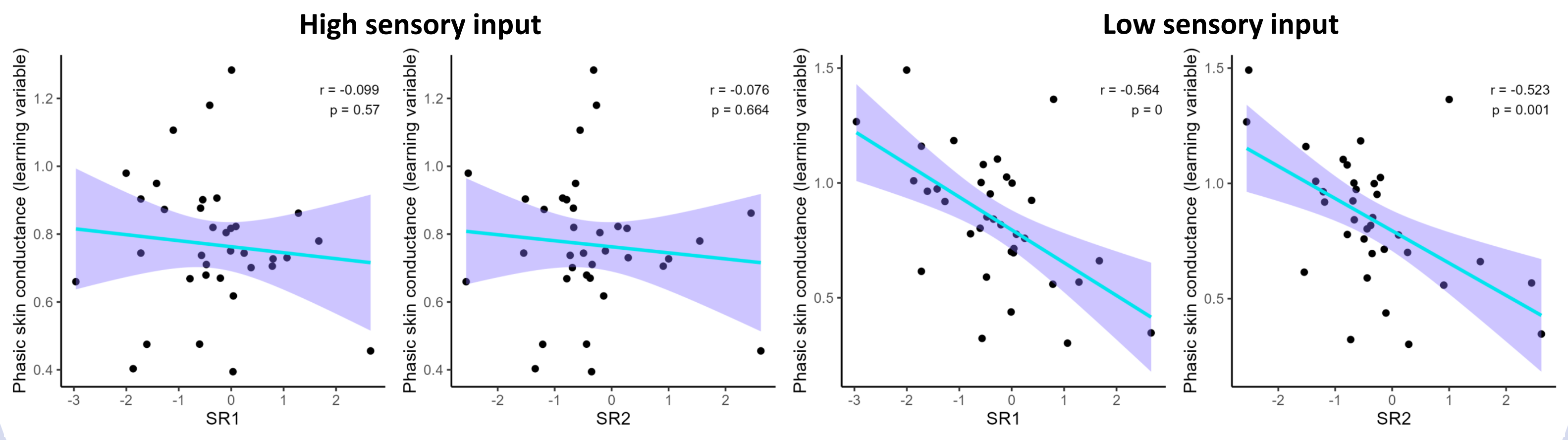
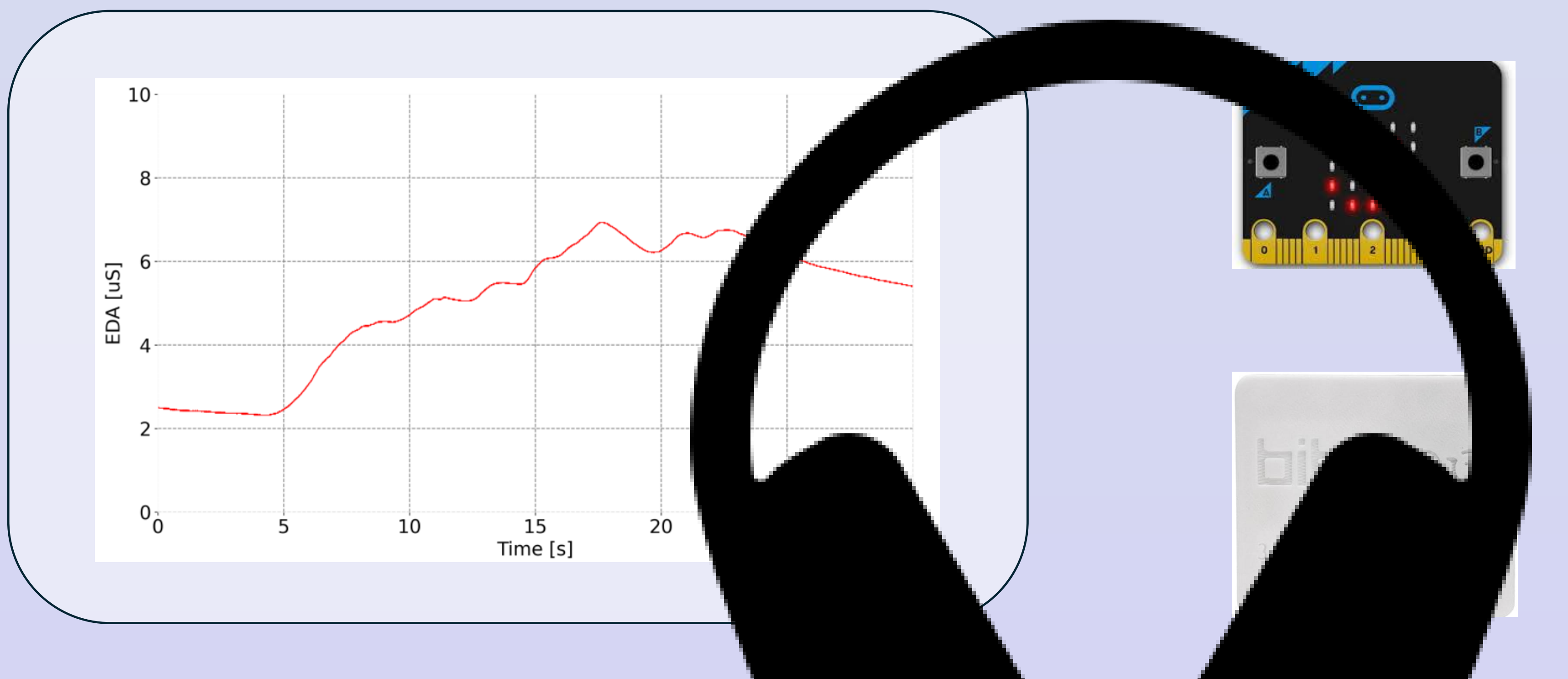


Figure 6. The separate regression plots of the phasic variable with either SR1 or SR2 in both the high and low sensory input classroom conditions show that the correlations were significant only in the low sensory input condition. Because the phasic variable correlates negatively with learning (Flø & Flø, in preparation), this indicates a learning benefit which correlates with the sensory responsivity levels in students in the low sensory input condition. This correlation is no longer significant when sensory input is higher. Moreover, neither tonic nor phasic variables demonstrated a significant group difference for high vs. low sensory input conditions when not sorted by sensory input.



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