Assessing the indirect effect of interface design via cognitive workload on a learning task

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Abstract

This study aimed to find whether human-machine interface indirectly influences the engagement level of students on learning tasks due to cognitive overload induced by the human-machine interface. This was examined by comparing two groups with different human-machine interface's for an online learning environment. The experimental design was created based on the design implications of Johnson (2013) to reduce cognitive workload, the other design was used in previous research. Eye-tracking and a questionnaire were used to subtract data about the cognitive workload and the engagement level of students. The results showed that the group with the experimental human-machine interface has significantly less cognitive workload. The results also showed that increased cognitive workload leads to an increased engagement level for the overall group, but not within groups. Due to the absence of a significant relationship between cognitive workload and engagement level within groups further research is recommended. We recommend that cognitive workload induced by the online learning platform is kept low by using the design implications of Johnson (2013).

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Introduction

Inquiry learning is an active form of learning wherein students are taught scientific reasoning, through performing scientific inquiries. This generally follows a cycle including five phases: orientation, conceptualization, investigation, conclusion and discussion (Keselman, 2003; Pedaste, 2015). Inquiry learning goes beyond memorization of scientific information and helps students gain deep conceptual knowledge (Bell, Urhahne, Schanze & Ploetznet, 2009). Inquiry activities are typically guided to help students structure their activities. Guided inquiry learning leads to better conceptual knowledge than traditional instruction (Plass et al., 2012; Eysink et al., 2009; D'Angelo et al., 2014), with less cognitive load for students (Whang & Wu & Zhuang & Huang, 2013).

Inquiry learning commonly uses software applications to let students do experiments that would be prohibitively expensive or unfeasible in a classroom (Hwang et al., 2013; Bell et al., 2009; Kroeze, 2019). Teaching inquiry learning with computer-simulated experiments combined with evaluation and guidance is promoted to be the most ideal for learning deep conceptual knowledge (Chinn & Malhorta, 2002). Go-Lab is an online platform that facilitates customized inquiry-based scientific learning environments with minimally intrusive guidance (Go Lab; Go-GA; de Jong & Sotiriou & Gillet, 2014). Kroeze et al. (2019; 2021) developed two adaptive feedback tools to support students in their inquiry learning process. Specifically, in students' creation of hypotheses and concept maps. Concept maps are graphical representation of a topic or process, expressed as a series of concepts and prepositions describing the relations between those concepts (Kroeze, 2021). With the development of Kroeze et al. (2019; 2021) adaptive feedback tools, the online learning environment can be more efficiently and effectively used for students individually.

Unfortunately, the adaptive feedback tools of Kroeze et al. (2019; 2021) were found to have a limited effect on the quality of students' inquiry learning and it appeared that about half of the students who had the option of requesting feedback never used the tools. The authors hypothesized that the students' lack of familiarity with Go-Lab required most of the students' attention which prevented them from using the feedback tools. The problems Kroeze et al. (2019; 2021) found corresponded with the initial problems of Go-Lab overall, which include usability problems regarding complex interfaces, a large amount of textual information, unclear and inseparable information presentation on the screen and lack of understandability of tools

(Go-Lab, 2013). Understandability, complex interfaces and unclear presentation of textual information are all part of the human-machine interface (HMI). HMI is known to influence cognitive processes, such as memory, perception, attention and learning which affects performance (Johnson, 2013; Rogers et al., 2011; Jarodzka, Gruber & Holmqvist, 2017). However, cognitive capacity is also needed for learning and learning does not take place when there is cognitive overload due to poor instructional design (Jarodzka, Gruber & Holmqvist, 2017; Wickens, 2008).

According to the Multiple Resource Theory (MRT), cognitive overload occurs when two tasks simultaneously use the same cognitive processing resources, leading to task interference (Wickens, 2002; 2008; McConnel & Quin, 2004; Smith & Buchholz, 1991).This means that the handling of poorly designed technical applications for learning can become a secondary task which occupies the same cognitive resources needed for learning. So, a complex HMI for the online learning environment could have hindered student's performance in the Kroeze et al. (2019; 2021) studies. The theoretical framework of Johnson (2013) provided design implications to create optimal assisting platforms, thus minimizing cognitive load from the system. These implications all consider a wide range of cognitive factors such as sensory perception and processing, reading, attention, memory and learning. in the present study, the HMI in Go-Lab created in Kroeze et al. (2021) study was revised in the current study using the design principles of Johnson (2013, see Appendix 1), resulting from the suspicion that the created HMI in Go-Lab is too demanding and interfering with the learning process.

The main deviations of the in Go-Lab created HMI from the design implications of Johnson (2013) appeared to concern textual representation, unclear images, noisy background, bad contrast, unfamiliar graphics, usages of modes and under-representation of the user goal. The first four deviations from the guidelines mainly revolved around the hindrance of automatic cognitive processes such as reading. Initially, reading requires various cognitive processes such as visual temporal processing and working memory (DeStefano & LeFevre, 2007; Baddeley, 2003, Solan et al., 2007, Johnson 2013). However, when reading is trained it becomes automated requiring less cognitive resources (Johnson, 2013; DeStefano & LeFevre, 2007). Nonetheless, automated cognitive reading processes can be hindered due to lengthy text, disfluencies, strong visual cues and hyperlinks which triggers the activation of analytic processing systems increasing the cognitive load (Potocki et al, 2017; White et al., 2010; DeStefano & LeFevre, 2007; Seufert et al., 2016; Lehmann, 2019; Alter et al., 2007; McConnel

& Quin, 2004). Therefore, an interface lay-out that avoids cognitively imposing textual representation and design, can offer a better reading experience, eventually leading to better performance (Al-Samarraie et al., 2019; DeStefano & LeFevre, 2007). Johnson’s (2013) guidelines also propose to minimize the need for reading and to optimize automatic processing for reading by avoiding patterned backgrounds, centering, or tiny fonds.

Unfamiliar graphics, usages of modes and under-representation of the user goals are a hindrance to information retrieval processing and memory. Graphics are easily learned and remembered due to the construction of mental models and the most preferred graphs are minimalistic and familiar (Rogers et al., 2011; Hou & Ho,2013; Rosen & Purionton, 2004; Jung & Myung, 2006: Harris, 2009). Unfamiliar graphics negatively affect the recognition and recollection of information stored in mental models (McDougall et al., 2001; Marchionini & Shneiderman, 1988). Additionally, users are goal-orientated and only pay attention to actions relevant to their goal, which further impairs their memory retrieval (Armentano & Amandi, 2011; Card et al., 1983; Johnson, 2013; Baddeley et al., 2011; Allen et al., 2012). Therefore, users tend to forget mode changes in systems while proceeding to pay attention to relevant user-goal activities (Johnson, 2013; Zimbardo & Johnson, 2017). Rogers et al. (2011) also advocate simplifying procedures that provoke cognitive memory overload. Johnson’s (2013) design implications propose to use familiar meaningful graphs and focusing on goal-orientation of users.

Research objective

This study investigates if HMI indirectly influences the engagement level of students on learning tasks due to the cognitive load induced by the HMI. The engagement level of students is the proactive attitude for learning, resulting in students spending more time on the learning task and actively asking for feedback. Too find if HMI indirectly influences engagement level two groups were compared, one group used the original HMI of the study of Kroeze et al. (2021); the other group worked with an HMI incorporating Johnsons’ (2013) design principles. Both designs incorporated the same learning tools, namely the concept mapper and the adaptive feedback tool. So, both groups used the same tool to organize and relate constructs of the learning material; were both able to request feedback from the system via the same format. The main differences between designs were the lay-out of the website, the amount of visual clutter and the amount of textual representation of information on the display, see figure 2 and 3 and appendix 1, 3 and 4.

A comparison of the cognitive workload and engagement level of students on learning tasks was made between groups. Considering visual attention as a major contributor to cognitive workload (RepovŠ & Baddeley, 2006), visual scanning behaviour was used to measure attentional shifts as an indicator for the objective cognitive workload. Additionally, subjective cognitive workload was measured via a questionnaire as an indicator for cognitive workload using the Multiple Research Questionnaire. The engagement level of the learning tasks was assessed by comparing the percentages of time spent looking at the concept map and the number of times the student asked for feedback.

Expected is that the control group with the original created HMI in Go-Lab would have a higher cognitive workload and a lower engagement level, compared to the experimental groups with a HMI incorporating Johnson's (2013) design implications. Thereafter, a negative association was expected between cognitive workload and engagement level. It was predicted that the negative association would differ within groups, whereby a larger negative regression coefficient for the control group was predicted. This was predicted, because the cognitively higher demanding HMI of the control group was expected to have a bigger impact on the engagement level then the cognitively less demanding HMI of the experimental group.

Method

Pilot study

The initial target group of this study were first-year secondary school students, which corresponded with the study of Kroeze et al. (2019; 2021). However, due to continuously changing regulations surrounding the ongoing SARS-COV-2 pandemic, recruitment was severely hindered. Eventually, a randomized controlled trial was conducted with last year VWO[1] students following a biology course. This study had already been approved by the ethical review board of the faculty of Behavioural Management and Social Science at the University of Twente. Further unexpected changes in regulations surrounding the SARS-COV-2 pandemic lead to a limited number of trial participants with unequal test environments. The unequal test environments were a consequence of shifting available classrooms, due to changing availability of participants in the pre-set time slots. The classrooms differed in distracting external factors, which made the distribution of distraction between participants differ. Therefore, this trial was regarded as a pilot study and it was decided to alter the study again to fit first-year university students, to which access was easier. Unless otherwise indicated, the remainder of this thesis describes the study executed with university students.

Participants

The experiment involved the participation of 22 first-year university students, which were randomly and equally divided into two groups. The control group had a mean age of 21.0; the experimental group had a mean age of 19.4. Participants were recruited via a university educational platform (Sona). This study was also approved by the ethical review board of the faculty of Behavioural Management and Social Science at the University of Twente. Participants gave consent via an online questionnaire at the start of the experiment. The inclusion criteria included being able to read and write Dutch, additionally participants needed to have had biology classes in secondary school.

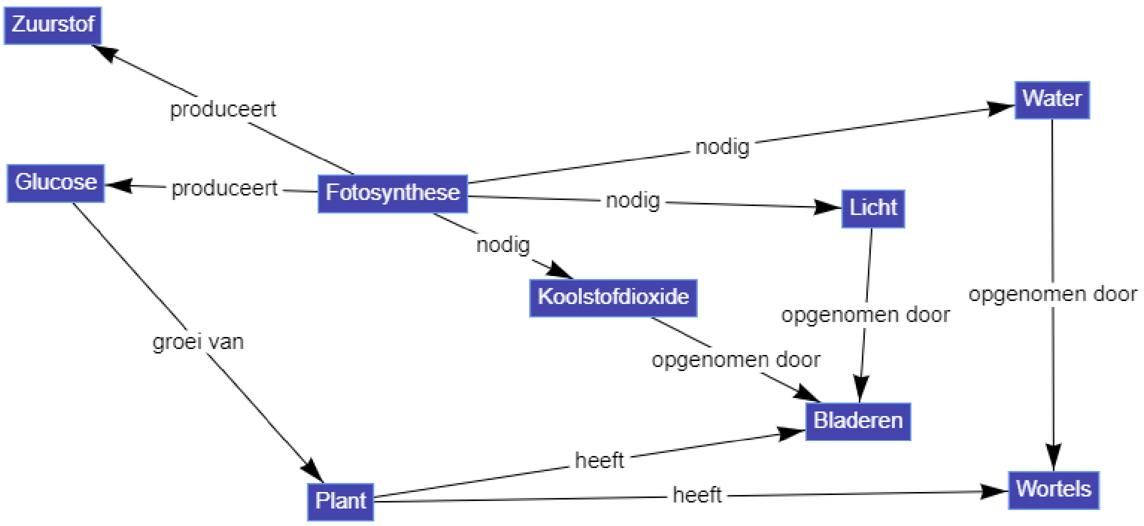
Task

All participants performed the same task, which consisted of making a concept map about the light reaction of photosynthesis in Go-Lab. Figure 1 shows a simplified example of a concept map of photosynthesis that was showed to the participants. The level of the assignment

[1] VWO is the highest level of Dutch secondary education, literally preparatory scientific education (voorbereidend wetenschappelijk onderwijs)

corresponded with the final exam material for VWO students and was created in collaboration with a VWO biology teacher. Concepts for this substantive learning material included photosystem 1 and 2, H+ ions, electrons, ATP-synthetase, P680, P700 and NADP+ reductase. Participants were first presented with information about photosynthesis and the light reaction of photosynthesis; then could continue making the concept map. The main difference between the groups was the HMI created in Go-Lab.

Figure 1, *The simplified example of a concept map for photosynthesis used in the experiment.*



<u>HMI created in Go-Lab</u>

The control group worked in a learning environment designed to be similar to the HMI used in the Kroeze et al. (2021) study; the experimental group worked with an HMI adjusted to the design guidelines of Johnson (2013). Table 1 shows an overview of the changes for the improved HMI design and the corresponding design principles of Johnson (2013). Two HMI's of Go-Lab were used, both incorporating the concept map and the adaptive feedback tool, see figures 2 and 3. For the overall HMI of the online platform, see appendices 1, 2 and 3.

Table 1. Design principles by Johnson (2013) and alterations made for the experimental design

Design principles Johnson (2013)	**Changes to the experimental HMI**
Minimize the need for reading	Minimizing instructional text
Visually emphasize to grab attention	Highlighting needed system instructions
Avoid information picking due to large textual presentation	Reduced substantive textual information by half
Format text into visual hierarchy	Changing textual information presentation
Use familiar navigation systems	Changing to L-inverted lay-out
Avoid patterned backgrounds, centring, or tiny fonds	Removing background noise
Use plain or simplified language	Removing unnecessary jargon
Use familiar graphics	Removing on-relevant/ non-common icons
Avoid bad contrasting that disrupt automatic reading	Giving feedback tool a fixed place to prevent bad contrasting
Avoid patterned backgrounds, centring, or tiny founds	Replacing unclear images

Figure 2*. The visual clutter containing HMI of the control group while constructing the concept map.*

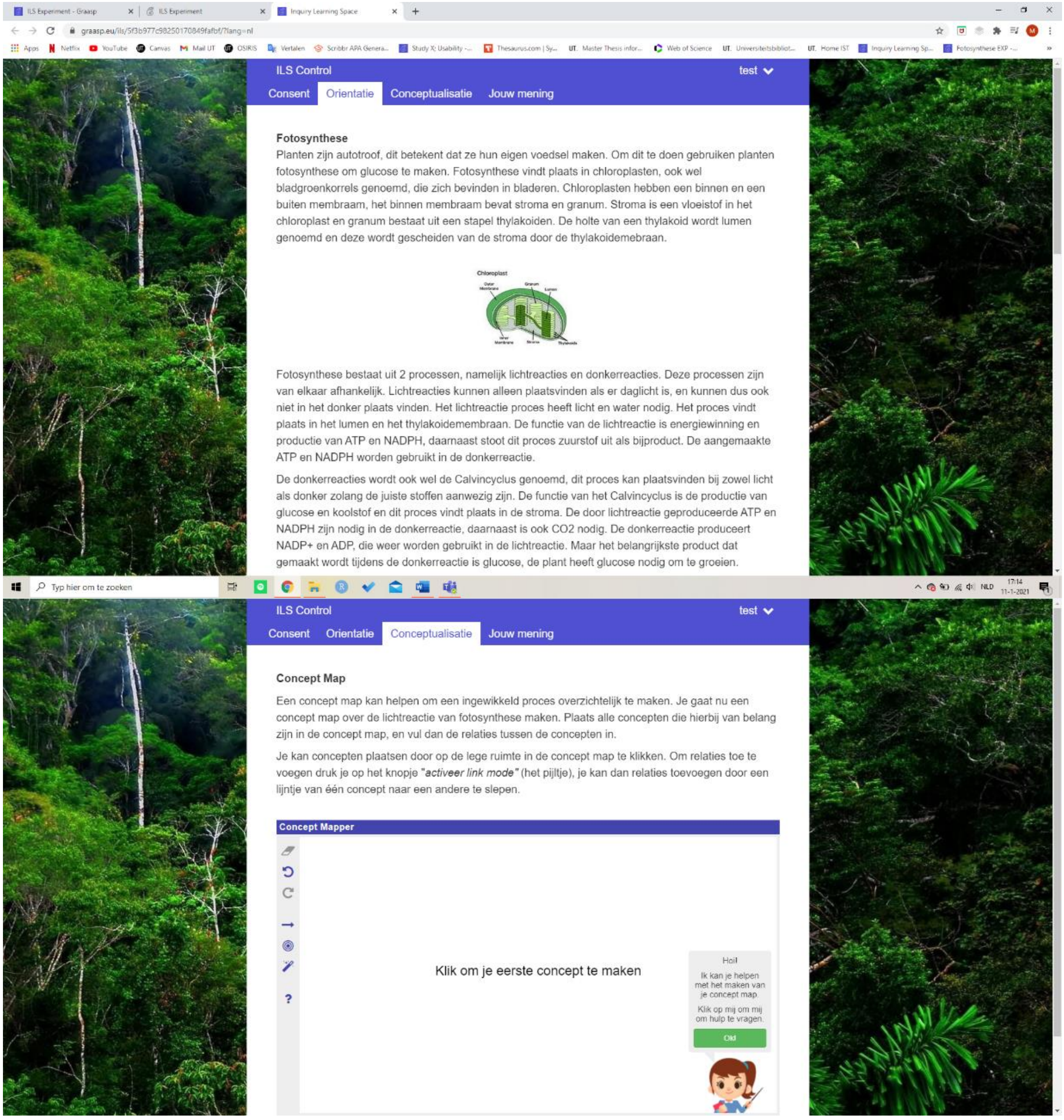
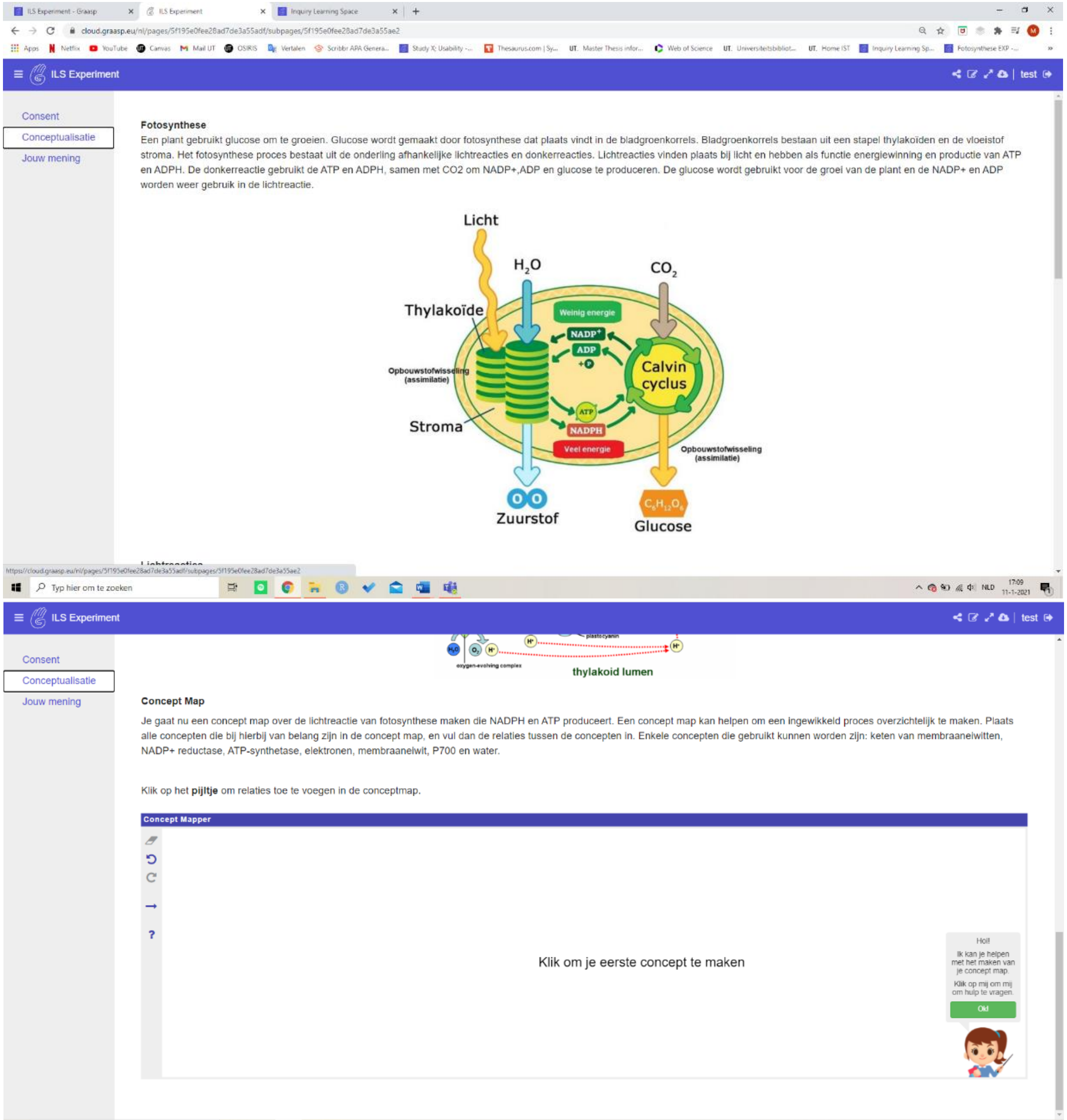


Figure 3. *The HMI of the experimental group based on Johnson's (2013) design implications while constructing the concept map.*



Ideally, the modes would have been removed because users only pay attention to goal-related tasks and easily forget mode changes (Armentano & Amandi, 2011; Card et al., 1983; Johnson, 2013). However, due to technical constraints this could not be altered and explanatory information about the system had to be available. Another technical constraint was that the new lay-out incorporated new functions in the right top corner as can be seen in figure 3, which could not be specifically removed for this study.

Procedure

Participants sat behind a table placed against a plain wall, in an experimental room with as few distractors as possible. Before starting the assignment, the researcher explained the purpose of the research and the presence of a camera. The adaptive feedback tool was not mentioned in the explanation, to prevent pointing attention to the adaptive feedback tool. Thereafter, participants were introduced to the eye-tracking (ET) equipment and were told to ignore them and focus on the task. Participants were then allowed to ask questions, after which the researcher calibrated the ET equipment and provided the participant with login credentials for the learning environment for Go-Lab. Participants were then presented with the consent form, after which the researcher left the room. After completing the consent form, the participants were instructed to proceed with the online learning task, and wave to the camera when finished. The researcher observed the participants through a camera, participants could not ask questions during the experiment. After finishing their task, the participants waved at the camera and the researcher came in to shut down the eye-tracking equipment. Finally, the researcher casually asked participants about their experience, and noted any additional unforeseen distracting variables.

Material

The main question in this research was whether cognitive workload induced by a poorly designed HMI of the Go-Lab system would influence students' level of engagement with the learning material. The cognitive load was split into subjective cognitive load and objective cognitive load.

Subjective cognitive load was measured via a combined selection of cognitive constructs from a translation of the Multiple Resources Questionnaire (MRQ), which is based on Wickens' multiple resource theory (Finomore et al., 2008). The subjective cognitive workload was calculated as the average workload of processes measured by the MRQ, which included visual lexical process, tactical figural process, spatial positional process, spatial emergent process, spatial concentrative process, spatial categorical process, spatial attentive process, short term memory process and manual process. Other questions about timing, auditory cues and facial expressions were not required in the experimental learning task and were therefore left out. Appendix 5 shows the questions which were considered not relevant for this study.

A back-translation method was used to verify the accuracy of the translation (Sperber, 2004). The back-translation method was performed by a certified bilingual teacher and a bilingual psychology student. Both back-translations can be found in the appendices 6 and 7. Both back-translated questionnaires showed high corresponding in the remaining translation (Forshaw, 2013). Then, a comprehension check was done with a VWO student, the student was asked to circle words that he did not know in the translated questionnaire. The results showed a lack of comprehension for the psychological jargon, as can be seen in Appendix 8. Therefore, the translated MRQ was tailored to the target group by removing headers of questions with psychological jargon when inserting the questionnaire into the Go-Lab questionnaire tool.

Objective cognitive load was measured by way of saccades per minute, as these are linked to visual attention (Mazer, 2011; Wollenberg et al., (2018). To measure the saccades the Tobii Fusion eye tracker was used whereby the data was required to have a minimum of 75% gaze samples. This non-invasive equipment was attached to the computer screen. Lastly, the engagement level of learning tasks was also split into two measurements. The first measurement was the relative amount of time participants spent looking at the concept map while performing the learning task. This was measured with the Tobii Fusion eye tracker. The second measurement was the number of clicks on the feedback tool, which derived from the log files of Go-Lab.

Measurement change

Before performing the analysis, the number of clicks on the feedback tool was dropped as an indicator for engagement level, as participants clicked an average of 0.82 and 1.91 times on the feedback, including clicks on the feedback introduction. This meant there was not enough data to perform meaningful statistical analyses with the measure. Participants explained after the experiment that they clicked on the introductory test to get rid of it, citing reasons such as ‘it was in the way’ or ‘it bothered me’ or ‘I thought it did not do anything’. Getting rid of the introductory text was counted and therefore could explain the minimalistic number of clicks found. Additionally, eye-tracking data of visual scanning behaviour confirmed that hardly any time was spent on looking at the adaptive feedback tool, see figure 4 and 5.

Figure 4. *Heat map of the relative duration of fixation on the learning task for the experimental design.*

Figure 5. *Heat map of the relative duration of fixation on the learning task for the control design.*

Data analyses

The data was collected through log dataof Go-Lab and the Tobii Fusion eye-tracker and consisted of mouse clicks on the adaptive feedback tool, responses on the MRQ and the eye-tracking data. All data was imported in R; participants who did not fill in the consent form were filtered out. Then, the variables subjective cognitive workload, objective cognitive workload and engagement level were constructed in R. Subjective cognitive workload was computed by computing the mean for the MRQ; Objective cognitive workload was constructed by calculating the saccades per minute and engagement level was computed by the percentage of time spent looking at the concept map. The reliability of the computed subjective cognitive workload was checked via a Cronbach's Alpha. Charts were used to visually identify outliers in the distribution of the data; outliers that were judged to be a measurement error were removed from the data. The measurements errors consisted inconsistent eye tracking data due to technical limitations.

To investigate the first hypothesis of this research a multivariate analysis (MANOVA) was performed, after an assumption check. The hypothesis was that cognitive workload and engagement level would differ between groups with different HMI's. Whereby the hypothesis states that the experimental group would have a lower cognitive workload and a higher engagement level compared to the control group. The independent grouping variable was HMI and the dependent variables were objective and subjective cognitive workload and engagement level. Afterwards, a discriminant function analysis was carried out to find the combined predicted value of engagement level, subjective and objective cognitive workload for group membership. If the MANOVA was significant, univariate analysis of variance (ANOVA) were performed to test the effect of HMI design on cognitive workload and engagement level separately.

The second hypothesis of this study was a negative relation between cognitive workload and engagement level. To investigate the second hypothesis a linear regression model was performed in R. Cognitive workload was the independent variable and engagement level the dependent variable. Additionally, a multi-level regression model was performed to investigate the difference in regression between groups. In this model the independent variable was the cognitive workload, the dependent variable engagement level and the grouping variable was the HMI, see Appendix 10 for the R script.

Results

First, the Cronbach's Alpha was 0.73 for the combined MRQ, however a higher Cronbach's Alpha of 0.80 was reached when the item manual processing was removed. After re-examining the items, manual processing was excluded, because this was the only physical item included that did not correspond with other cognitive demanding items.

Difference between groups with different HMI's

Before performing a MANOVA the assumptions of the MANOVA were checked in R for the MRQ, the saccades per minute and the percentage time spent on the concept map. The assumption were the linearity of dependent variables, normal distribution of the dependent variables and multivariate homogeneity of variance within and between groups. The data showed no reason to assume that the assumptions were not met; therefore, continuing to execute a MANOVA. The MANOVA showed a significant difference between groups with different HMI's $F(2, 20) = 4.70$, p = .013. The means of each variable was higher for the control group compared to the experimental group (Tables 1).

Table 1

Means and 95% confidence interval per group of the self-rated Multiple Resource Questionnaire , the saccades per minute and the percentage of time spent on the concept map.

Group	***Mean subjective cognitive load:*** ***MRQ questionnaire***	***Mean objective cognitive load:*** ***Saccades per minute***	***Mean engagement level:*** ***Percentage time spent on the Concept Map***
Control	3.31 (2.84 - 3.79)	78.55* (68.20 - 88.90)	46.55 (41.40 - 51.71)
Experimental	2.97 (2.54 - 3.49)	49.29* (41.77 - 62.47)	38.85 (35.25 - 45.55)

Only one participant with outliers on al variables was removed due to the influence of eye disorder of -3,5, which affected the measurements of eye-tracking (Dahlberg,2010).

** Also significantly different on ANOVA*

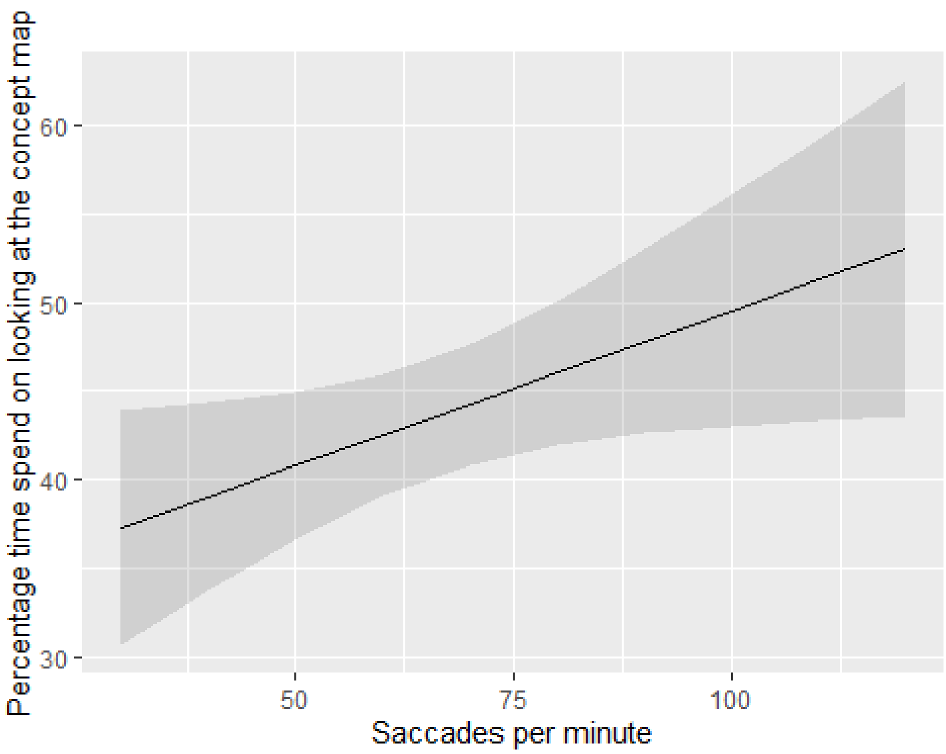
The discriminant function analysis showed an accuracy rate of 86.4%. This indicates that the MRQ, the saccade per minute and percentage time spent on the concept map can predict with 86.4% accuracy the group of a participant.

When performing the three separate ANOVA's only objective cognitive load, measured as the saccades per minute, was found to have a significant difference between groups $F(1, 20) = 14.2$, p = .0012. with the control group having a mean of 26.4 more saccades per minute than to the experimental group.

Relation between cognitive workload and engagement level

To examine whether there was a negative relationship between cognitive workload and engagement level a linear regression model was performed for all participants. This model showed that the objective cognitive workload, saccades per minute, explained 14% of the variance in engagement levels ($F(1, 20) = 4.49$, $p = .047$, $R^2 = .14$). Saccades per minute is a significant predictor for the proportion of time spent on looking at the concept map ($ß = .18$, $t = 2.12$, $p = .047$). Figure 6 shows the positive linear association between saccades per minute and the percentage of time spent looking at the concept map.

Figure 6. *Linear relationship between saccades per minute and percentage time spent on the concept map for the overall participant group (The grey shaded area represents the standard error)*



A post-hoc linear regression analysis within groups showed no significant effect of objective and subjective cognitive workload on engagement level. However, the units for cognitive workload, saccades per minute and the MRQ, showed contradicting associations with percentage time spent on the concept map. Namely, a positive relation between saccades per minute and percentage time spent on the concept map. Against a negative relation between the MRQ and percentage time spent looking at the concept map.

Discussion

This study was aimed at finding whether HMI indirectly influences the engagement level for a learning task by inducing cognitive overload. Therefore, two different HMI’s created in Go-Lab were compared. The existing Go-Lab HMI used in Kroeze et al (2021) was compared to an improved Go-Lab HMI. The improved HMI was created using Johnson’s (2013) design principles to stimulate less demanding automatic cognitive processing. We expected that the improved HMI would result in a lower cognitive workload and a higher engagement level compared to the original HMI created in Go-Lab. In addition, a negative correlation was expected between cognitive workload and engagement level. These expectations were tested by comparing the two HMI’s in a randomized control trial.

A significant difference between the two groups was found in which cognitive workload was the main indicator, but there was no significant difference in engagement levels between the two groups. The group with the original created HMI in Go-Lab had a significant higher objective cognitive workload compared to the group with the improved HMI in Go-Lab. This can be explained by the fact that the original Go-Lab HMI had little consideration for the cognitive processes needed for reading, such as visual encoding processes. The lengthy textual information, disfluencies and visual noise which were incorporated in the original HMI in Go-Lab hindered the automatic visual processing and activated higher demanding analytic cognitive resources (Seufert et al., 2016; Lehmann, 2019; Alter et al., 2007; Johnson, 2013; McConnel & Quin, 2004). On the other hand, the improved HMI which incorporated Johnson’s (2013) design guidelines stimulated less demanding automatic cognitive processing that reduced the cognitive workload induced by the HMI.

A significant positive association was found between cognitive workload and engagement level, however no association was found within groups. This means that generally, a higher cognitive workload is associated with a higher engagement level. This contradicted the predicted negative association between cognitive workload and engagement level. A positive association between cognitive workload and engagement level is known in the literature, however this is only in the starting phase of learning new knowledge (Lei et al., 2018; Richey & Nokes-Malach, 2014). Cognitive workload reduces over time when knowledge is practiced because the practice of knowledge allows for less cognitively demanding procedural information processing, leaving more opportunity for analytic cognitive processes (Rittle-Johnson et al., 2001; Richey & Nokes-Malach, 2014; Sala & Gobet, 2019; Zimbardo & Johnson, 2017). However, in this study the substantive content was a prerequisite for participation, meaning that the initial learning phase of the substantive content had already passed for al participants.

We suspect that the positive association between cognitive workload and engagement level in this study can be explained by unfamiliarity with concept maps. Nearly all participants were unfamiliar with concept maps and making concept maps requires cognitive elaboration. Schroeder et al. (2017) hypothesized that the cognitive load associated with making concept maps reduces with experience, therefore leaving more cognitive capacity for substantive content. This hypothesis corresponds with the initial cognitive workload distribution of learning new knowledge (Richey & Nokes-Malach, 2014) and therefore seems like a credible explanation for the positive association between cognitive workload and engagement level in this study. Nevertheless, research on cognitive workload while making concept maps is limited and would need to be further investigated to be proven (Schroeder et al., 2017).

This study showed that the literature-based design implication of Johnson (2013) have a beneficial effect on cognitive workload and can be recommended to help create HMI's that places minimal cognitive demands on students and to fix the usability problems Go-Lab (2013) reported regarding complex interfaces, a large amount of textual information, unclear and inseparable information presentation on the screen and lack of understandability. We suggest that designer's and teachers use the following guidelines:

1. Do not use patterned backgrounds, centring, or tiny fonts that hamper visual encoding processes (Johnson, 2013; Solan et al., 2007; McConnel & Quin, 2004; Al-Samarraie et al., 2019; DeStefano & LeFevre, 2007).
2. Make a system familiar to the users by using familiar recognizable graphs, because recognition is cognitively less demanding for information retrieval (Johnson, 2013; McDougall et al., 2001; Marchionini & Shneiderman, 1988; Harris, 2009; Rogers et al., 2011; Hou & Ho,2013; Rosen & Purionton, 2004; Jung & Myung, 2006)

3. Minimize the need for reading, because this requires multiple cognitive processes, such as visual encoding and temporal processing and working memory (Johnson, 2013; DeStefano & LeFevre, 2007; Baddeley, 2003, Solan et al., 2007).
4. Use hierarchical text presentation and avoid lengthy text that overwrites automated reading processing and triggers cognitive reading strategies (Johnson, 2013; Potocki et al, 2017; White et al., 2010)
5. Use familiar terminology and avoid uncommon terminology that triggers cognitively demanding analytic processing systems (Johnson, 2013; Anderson, 2009; Lehmann, 2019; Alter et al., 2007; Seufert et al., 2016).
6. Avoid modes and keep user goal in mind when highlighting information, because users are goal-orientated and only pay attention to relevant information due to limited attention and memory capacity (Johnson, 2013; Armentano & Amandi, 2011; Card et al., 1983; Baddeley et al., 2011; Allen et al., 2012; Zimbardo & Johnson, 2017; Rogers et al., 2011)

Regarding the observed positive association between engagement level and cognitive workload more research is needed as this association raises questions regarding the effect of the design on engagement level. Research is needed to clarify the lack of a significant association between cognitive workload and engagement level within groups. Additionally, the novelty of making concept maps could have added an additional difficulty dimension to the predetermined substantive content, which was not anticipated. Therefore, it is highly recommended to further investigate the effect of design on engagement level and the correlation between cognitive workload and engagement level.

The initial cause for this research was the non-usage of the adaptive feedback tool, whereby the usability problems were speculated to be the cause. This study initially included a measure from the adaptive feedback tool to determine the engagement level with that tool specifically. Unfortunately, the engagement with the adaptive feedback tool was so low that it had to be removed. The results of the minimalistic engagement with the adaptive feedback tool in this study corresponds with the results of Kroeze et al. (2021). Therefore, the explanation of the non-usage of the adaptive feedback tool is still undetermined.

Nevertheless, the eye-tracking data and the notes from the researcher did provide new information about the non-usage of the adaptive feedback tool. The visualization of the eye-tracking data showed that participants hardly looked at the adaptive feedback tool, in both HMI designs. Participants also stated multiple reasons for not using the adaptive feedback tool such as ‘I thought it did not do anything’, ‘it was in the way’ and ‘it bothered me’. These comments were made based on students’ initial reactions to the adaptive feedback tool, without any meaningful interactions with the tool. We suspect that students had preconceptions about the automated feedback tool based on their previous interactions with similar avatars and chat bots, but were unfamiliar with the functionality of the adaptive feedback tool. AI tools are developmental and consequently sometimes it is unclear for users what AI tools can do (Chaves & Gerosa, 2020; Zamora, 2017). Because there is a dearth of research on the usage and non-usage of AI tools (Brandtzaeg & Følstad, 2018), we recommend explorative research into students perceptions of the adaptive feedback tool.

Concluding from this research it can be stated that HMI has an effect on cognitive workload, and that cognitive worklaod effects engagement level. However, the effect of cognitive workload on engagement level needs further clarification, and is likely to be highly dependent on the context of the students and the learning materials and HMI design.

Limitations

The main limitation in this research was a consequence of the SARS-COV-2 pandemic. Due to changing regulations, the recruitment of participants was hindered. To still execute the study, the target group had to change multiple times leading to changes in the overall experiment. The substantive content had to be adjusted multiple times, to fit the new target group. This led to more complicated substantive content and concept maps than in the originally intended experiment, which was suppose to use the same target group as the studies of Kroeze et al. (2019; 2021). While no substantive influences are suspected in the results, the constantly changing regulations resulted in a small sample size for this experiment.

Another limitation in this research originated from the overarching Go-Lab framework design. Because the functionalities needed for the learning task had to be equal, Go-Lab was used for both the experimental group and the control group. This resulted in technical constraints regarding the HMI leading to limited implementation of the design principles from Johnson (2013). The main limitation was that the functionalities could not be adjusted in the Go-Lab platform and therefore modes were still used.

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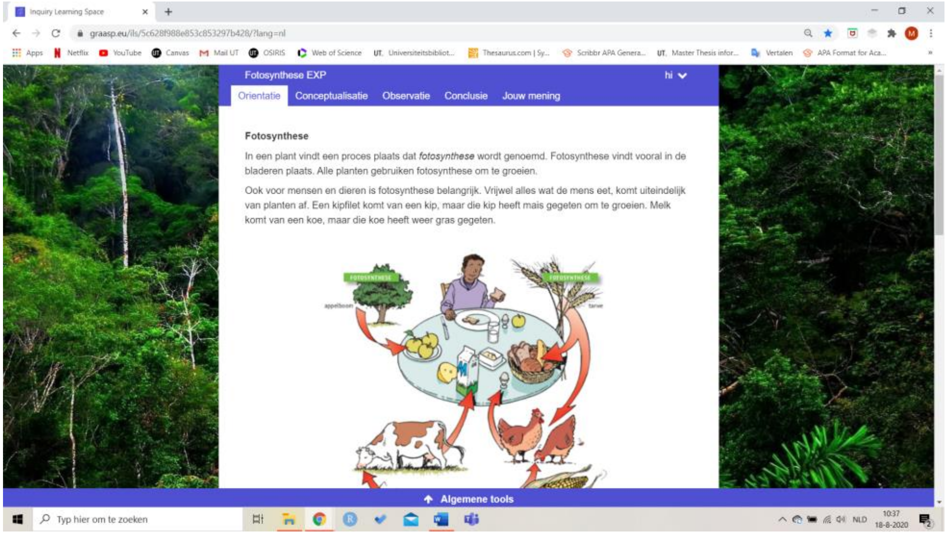
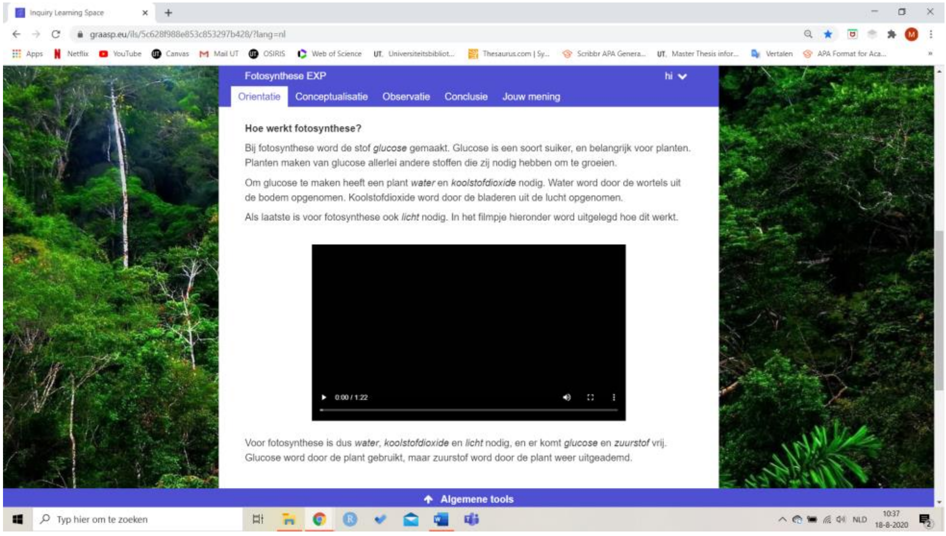
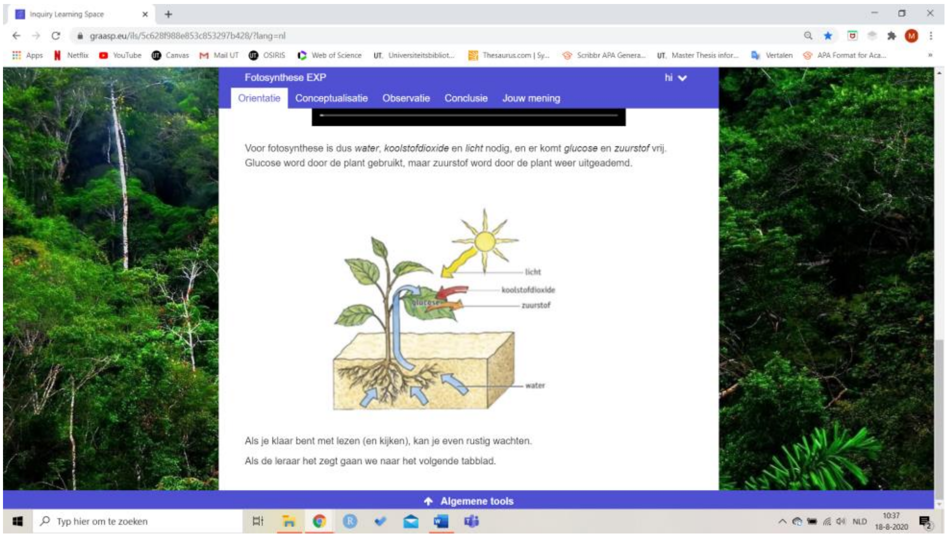
Appendix 1 Revision of Go-Lab platform

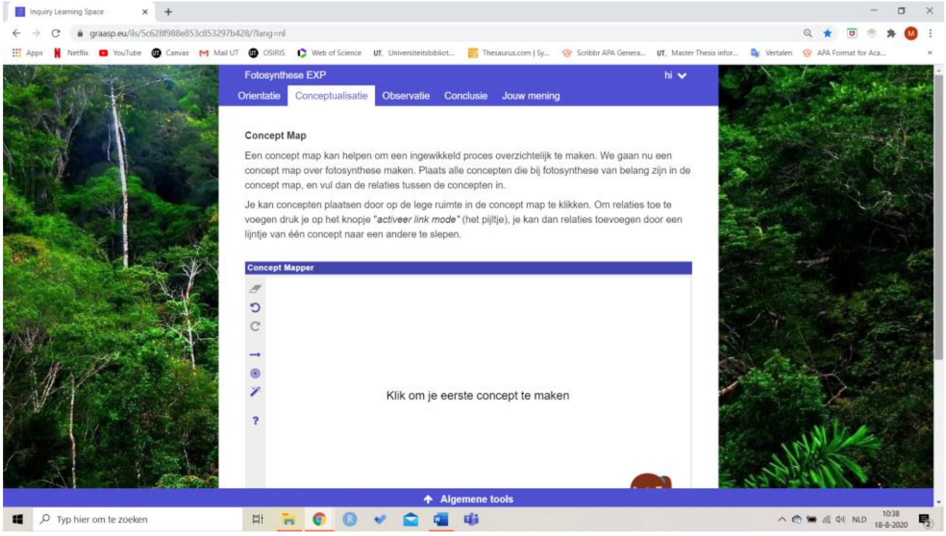
Guidelines Johnson (2013)	Additional sources	Original/Control design	Experimental Design
Minimize the need for reading, because this requires multiple cognitive processes, such visual encoding and temporal processing and working memory	(DeStefano & LeFevre, 2007; Baddeley, 2003, Solan et al., 2007)	Unnecessary lengthy instructional texts	Reducing of words in explanations
Avoid lengthy text that overwrite automated reading processing and triggers cognitive reading strategies	(Potocki et al, 2017; White et al., 2010).	Lengthy substantive content with lots of unnecessary context	Reducing of textual information two half of the original textual information in the substantive context
Avoid uncommon terminology, which triggers analytic processing systems which demand more cognitive recourses	(Anderson, 2009; Lehmann, 2019; Alter et al., 2007; Seufert et al., 2016).	The textual information used uncommon terminology that users had not heard before	Simplified all words, only leaving the technical terms that are not replaceable
Do not use patterned backgrounds, centring or tiny fonds that intervenes with visual encoding processing	(Solan et al., 2007; McConnel & Quin, 2004; Al-Samarraie et al., 2019; DeStefano & LeFevre, 2007).	This platform had a noisy background, tiny fonds in informative images and centring of text	Lay-out change, removal of image background, removal of tiny fonds in informative images and removal of centred textual representation
A systems should be made familiar by using familiar graphs, because recognition is cognitive less demanding for information retrieval.	(McDougall et al., 2001; Marchionini & Shneiderman, 1988; Harris, 2009; Rogers et al., 2011; Hou & Ho,2013; Rosen & Purionton, 2004; Jung & Myung, 2006)	Usage of unfamiliar icons for unfamiliar icons	Removal of unnecessary functions and removal of uncommon icons.
Avoid modes and keep user goal in mind when highlighting information, because users are goal-orientated and only pay attention to relevant information due to limited attention and memory capacity	(Armentano & Amandi, 2011; Card et al., 1983; Baddeley et al., 2011; Allen et al., 2012; Zimbardo & Johnson, 2017; Rogers et al., 2011)	Usages of modes, with unclear highlighting of information in lengthy instructions	Removal of extensive and clearer highlighting of necessary instructions. Due technical limitations the mode could unfortunately not be removed

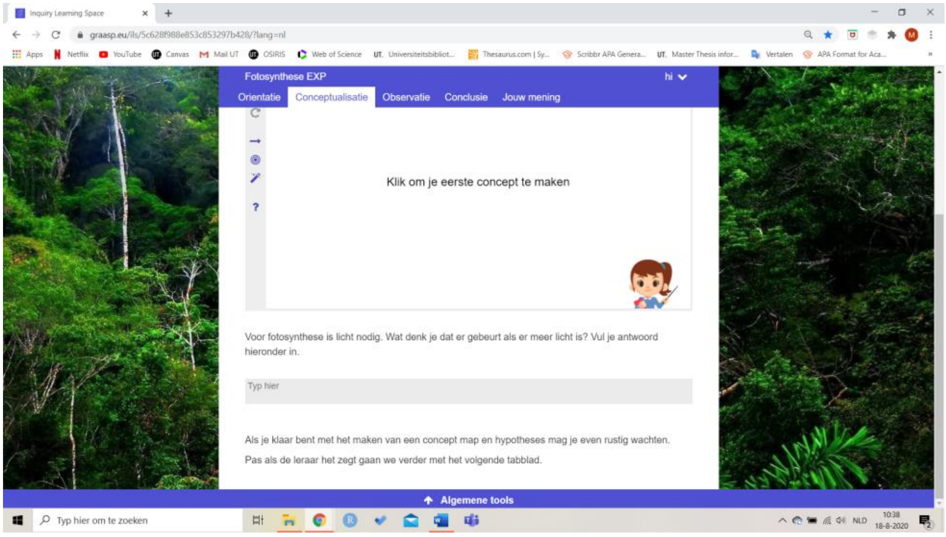
Appendix 2 Original Design



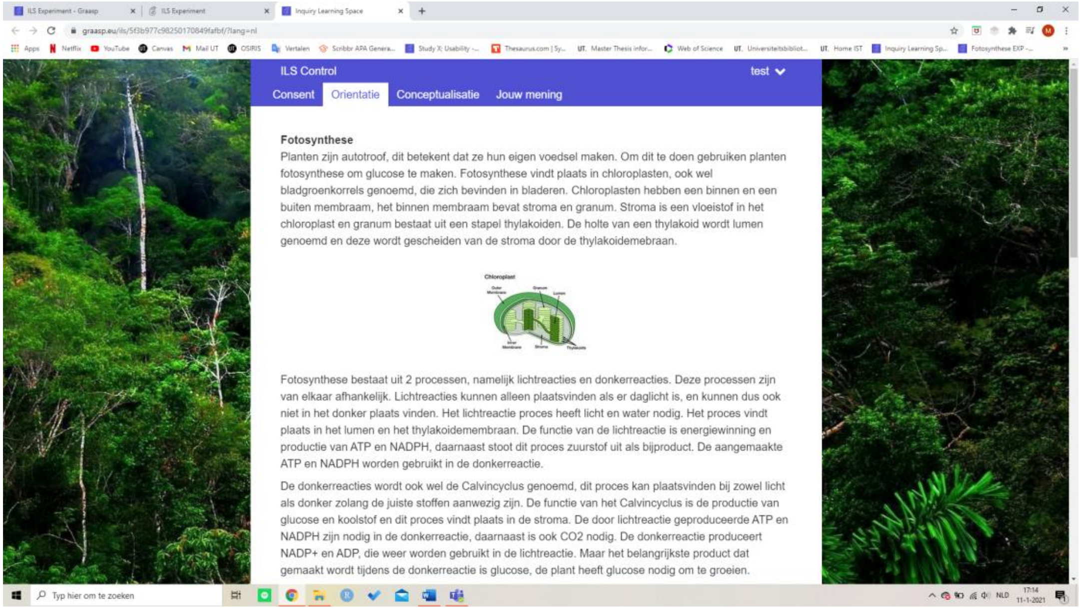


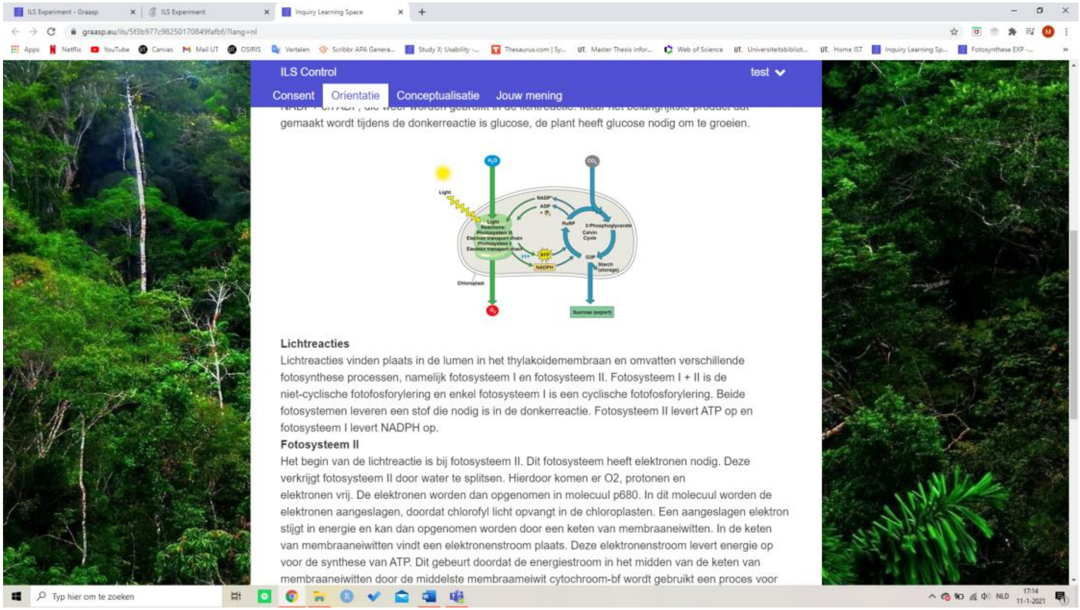


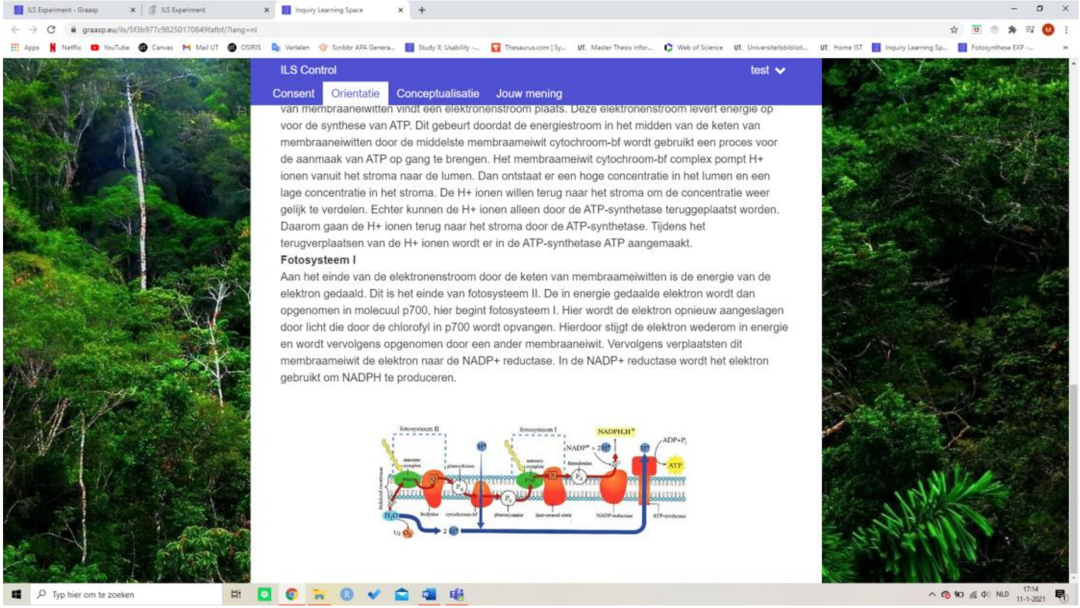

Inquiry Learning Space
graasp.eu/ils/5c628f988e853c853297b428/?lang=nl
Fotosynthese EXP
Orientatie
Conceptualisatie
Observatie
Conclusie
Jouw mening
Concept Map
Een concept map kan helpen om een ingewikkeld proces overzichtelijk te maken. We gaan nu een concept map over fotosynthese maken. Plaats alle concepten die bij fotosynthese van belang zijn in de concept map, en vul dan de relaties tussen de concepten in.
Je kan concepten plaatsen door op de lege ruimte in de concept map te klikken. Om relaties toe te voegen druk je op het knopje "activeer link mode" (het pijltje), je kan dan relaties toevoegen door een lijntje van één concept naar een andere te slepen.
Concept Mapper
Klik om je eerste concept te maken
Algemene tools
Typ hier om te zoeken

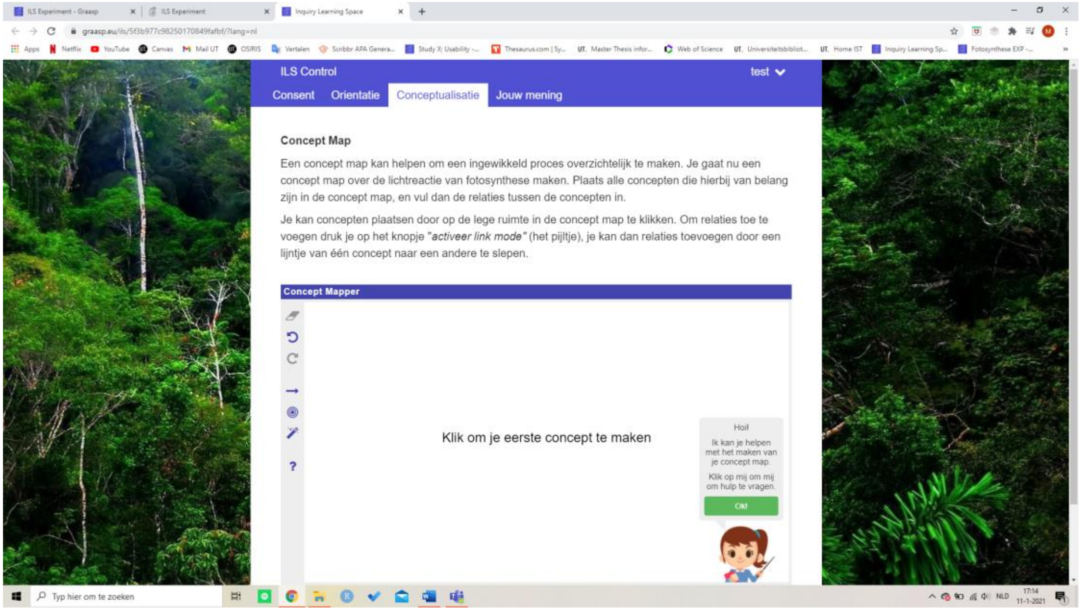

Inquiry Learning Space
graasp.eu/ils/5c628f988e853c853297b428/?lang=nl
Fotosynthese EXP
Orientatie
Conceptualisatie
Observatie
Conclusie
Jouw mening
Klik om je eerste concept te maken
Voor fotosynthese is licht nodig. Wat denk je dat er gebeurt als er meer licht is? Vul je antwoord hieronder in.
Typ hier
Als je klaar bent met het maken van een concept map en hypotheses mag je even rustig wachten.
Pas als de leraar het zegt gaan we verder met het volgende tabblad.
Algemene tools
Typ hier om te zoeken

Appendix 3 Control Design

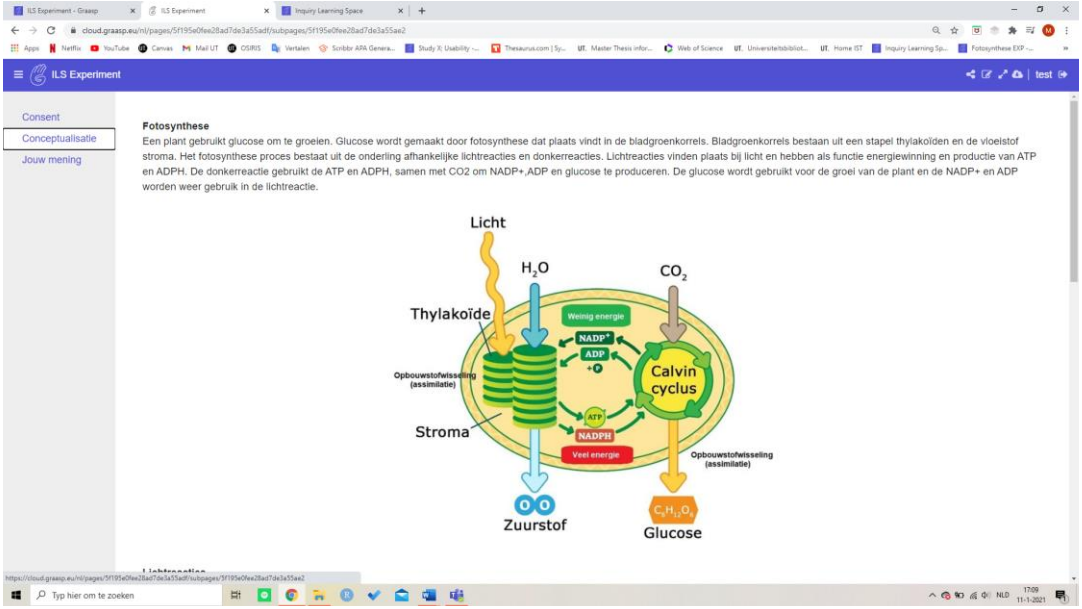


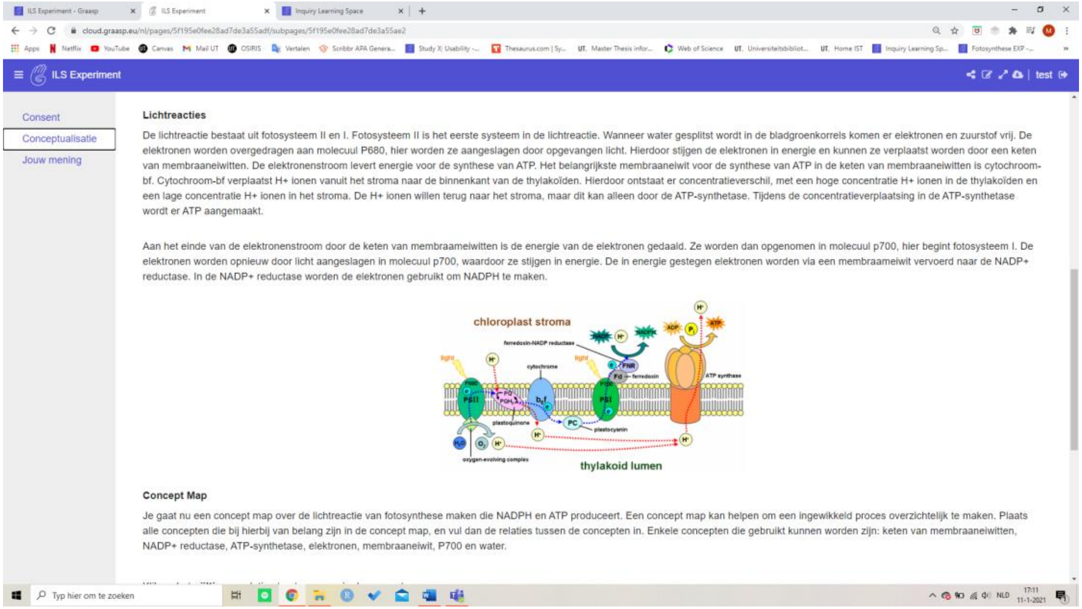


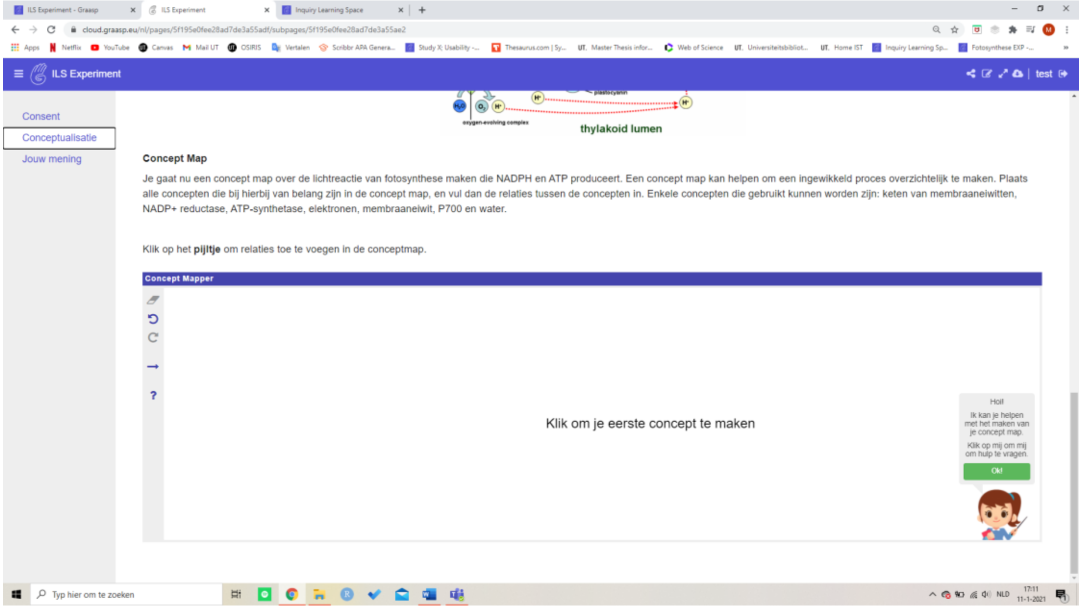

ILS Control
test
Consent
Orientatie
Conceptualisatie
Jouw mening
van membraaneiwitten vindt een elektronenstroom plaats. Deze elektronenstroom levert energie op voor de synthese van ATP. Dit gebeurt doordat de energiestroom in het midden van de keten van membraaneiwitten door de middelste membraameiwit cytochroom-bf wordt gebruikt een proces voor de aanmaak van ATP op gang te brengen. Het membraameiwit cytochroom-bf complex pompt H+ ionen vanuit het stroma naar de lumen. Dan ontstaat er een hoge concentratie in het lumen en een lage concentratie in het stroma. De H+ ionen willen terug naar het stroma om de concentratie weer gelijk te verdelen. Echter kunnen de H+ ionen alleen door de ATP-synthetase teruggeplaatst worden. Daarom gaan de H+ ionen terug naar het stroma door de ATP-synthetase. Tijdens het terugverplaatsen van de H+ ionen wordt er in de ATP-synthetase ATP aangemaakt.
Fotosysteem I
Aan het einde van de elektronenstroom door de keten van membraameiwitten is de energie van de elektron gedaald. Dit is het einde van fotosysteem II. De in energie gedaalde elektron wordt dan opgenomen in molecuul p700, hier begint fotosysteem I. Hier wordt de elektron opnieuw aangeslagen door licht die door de chlorofyl in p700 wordt opvangen. Hierdoor stijgt de elektron wederom in energie en wordt vervolgens opgenomen door een ander membraaneiwit. Vervolgens verplaatsten dit membraameiwit de elektron naar de NADP+ reductase. In de NADP+ reductase wordt het elektron gebruikt om NADPH te produceren.
fotosysteem II
fotosysteem I
NADPH,H+
ADP+Pi
ATP


ILS Control
test
Consent
Orientatie
Conceptualisatie
Jouw mening
Concept Map
Een concept map kan helpen om een ingewikkeld proces overzichtelijk te maken. Je gaat nu een concept map over de lichtreactie van fotosynthese maken. Plaats alle concepten die hierbij van belang zijn in de concept map, en vul dan de relaties tussen de concepten in.
Je kan concepten plaatsen door op de lege ruimte in de concept map te klikken. Om relaties toe te voegen druk je op het knopje "activeer link mode" (het pijltje), je kan dan relaties toevoegen door een lijntje van één concept naar een andere te slepen.
Concept Mapper
Klik om je eerste concept te maken
Hoi!
Ik kan je helpen met het maken van je concept map.
Klik op mij om mij om hulp te vragen.
Ok!

Appendix 4 Experimental Design






ILS Experiment
Consent
Conceptualisatie
Jouw mening
thylakoid lumen
Concept Map
Je gaat nu een concept map over de lichtreactie van fotosynthese maken die NADPH en ATP produceert. Een concept map kan helpen om een ingewikkeld proces overzichtelijk te maken. Plaats alle concepten die bij hierbij van belang zijn in de concept map, en vul dan de relaties tussen de concepten in. Enkele concepten die gebruikt kunnen worden zijn: keten van membraaneiwitten, NADP+ reductase, ATP-synthetase, elektronen, membraaneiwit, P700 en water.
Klik op het pijltje om relaties toe te voegen in de conceptmap.
Concept Mapper
Klik om je eerste concept te maken
Hoi!
Ik kan je helpen met het maken van je concept map.
Klik op mij om mij om hulp te vragen.
Ok!

Appendix 5 Original MRQ

All red marked questions were considered non-relevant for tis study.

Multiple resource questionnaire

The purpose of this questionnaire is to characterize the nature of the mental processes used in the task with which you have become familiar. Below are the names and descriptions of several mental processes. Please read each carefully so that you understand the nature of the process. Then rate the task on the extent to which it uses each process, using the following scale

No usage	Light usage	Moderate usage	Heavy usage	Extreme usage

Important:

All parts of the process definition should be satisfied for it to be judged as having been used. For example, recognizing geometric figures presented visually should not lead you to judge that the ‘Tactile figural’ process was used, just because figures were involved. For that process to be used, figures would need to be processes tactilely (i.e., using the sense of touch).

Please judge the task as whole, averaged over the time you performed it. If a certain process was used at one point in the task and not at another, your rating should not reflect ‘peak usage’ but should instead reflect average usage over the entire length of the task

---

Auditory emotional process

Required judgments of emotion (e.g., tone of voice or musical mood) presented through the sense of hearing.

Auditory linguistic process

Required recognition of words, syllables, or other verbal parts of speech presented through the sense of hearing.

Facial figure process

Required recognition of faces, or of the emotions shown on faces, presented through the sense of vision.

Facial motive process

Required movement of your own face muscles, unconnected to speech or the expression of emotion.

Manual process

Required movement of the arms, hands, and/or fingers.

Short term memory process

Required remembering of information for a period of time ranging from a couple of seconds to half a minute.

Spatial attentive process

Required focusing of attention on a location, using the sense of vision.

Spatial categorical process

Required judgement of simple left-versus-right or up-versus-down relationships, without consideration of precise location, using the sense of vision.

Spatial concentrative process

Required judgment of how tightly spaced are numerous visual objects or forms.

Spatial emergent process

Required ‘picking out’ of a form or object from highly cluttered or confusing background, using the sense of vision.

Spatial positional process

Required recognition of a precise location as differing from the other location, using the sense of vision.

Spatial quantitative process

Required judgement of numerical quantity based on a nonverbal, nondigital representation (for example, bar graphs or small clusters of items), using the sense of vision.

Tactile figural process

Required recognition or judgment of shapes (figures, using the sense of touch.

Visual lexical process

Required recognition of words, letters, or digits, using the sense of vision.

Visual phonetic process

Required detailed analysis of the sound of words, letters, or digits presented using the sense of vision.

Visual temporal process

Required judgement of time intervals, or of the timing of events, using the sense of vision.

Vocal process

Required use of your voice

Appendix 6 Back-translation MRQ of certified English teacher

The multiple resources questionnaire
The purpose of this questionnaire is researching the characteristics of mental processes. Below one can see the names and descriptions of different mental processes. Read them carefully, so that you understand the mental process. Subsequently, assess how much each mental process is used in the assignment with the help of the following scale:

No usage	Light usage	Mediocre usage	Frequent usage	Extreme usage

Important:
All parts of the mental process definition must have been used to be able to tell this has been used. For example, the recognition of visual figures should, for example, not lead to the conclusion that the ‘Tactile figures’ process has been used only because the word figures is there. To use the ‘tactile figures’ process, figures must be processed in a tactile manner (which means using your sense of touch and feeling figures).

Assess the assignment as a whole, averaged over the time you have performed it. If you have used a mental process sometimes and if you have not used a mental process sometimes, assess the average use during the whole assignment.

1 Auditory emotional process
Requires recognition of emotion (for example, tone or musical tuning) presented via hearing.

2 Auditory linguistic process
Requires recognition of words, syllables or other verbal parts of speech that are presented via hearing.

3 Facial figure process
Requires seeing and recognising faces or emotions that are shown on faces.

4 Facial motivational process
Requires using your facial muscles, excluding speech or expressing emotions.

5 Manual process
Requires using movements of the arms, hands and/or fingers.

6 Short term memory process
Requires remembering information during a period varying between a few seconds and half a minute.

7 Spatial awareness process
Requires aiming focus on one location with the help of vision.

8 Spatial categorical process
Requires seeing simple left-versus-right or up-versus-down relations, without taking the exact location into account.

9 Spatial concentration process
Requires seeing how close numerous objects or shapes are.

10 Spatial rising process
Requires ‘picking out’ a shape or object to look at from a very messy or confusing background.

11 Spatial positional process
Requires seeing and recognising a precise location as different from another location.

12 Spatial quantitative process
Requires seeing and assessing numerical magnitude based on a non-verbal, non-digital display (for example, bar charts or small clusters of items).

13 Tactile figurative process
Requires feeling and recognising or assessing shapes (figures)

14 Visual lexical process
Requires seeing and recognising words, letters or numbers.

15 Visual phonetic process
Requires the use of detailed analysis of the sound of words, letters or numbers that you see.

16 Visual temporal process

Requires assessing time intervals, or the timing of events with the help of vision.

17 Vocal process

Requires the use of your voice.

Appendix 7 Back-translation MRQ of bilingual psychology student

The multiple resources questionnaire

The goal of this questionnaire is to examine the characteristics of mental processes. Below are some names and descriptions of different mental processes. Read these carefully, so you understand the mental process. Judge accordingly how many each mental process is used in the assignment, supported by the following scale:

No usage	Light usage	Mediocre usage	A lot of/significant usage	Extreme usage

Important:

All subjects of the mental process definition should be used to be able to say that it is used. For example, the recognition of visual figures would, for example, not lead you to judge that the 'Tactile figures' process is used only because the word figures is in there. To be able to use the 'Tactile figures' process, figures have to be processed in a tactile manner (i.e. that you use your tactile sense and feel figures).

Judge the assignment as a whole, averaged over the time you conducted it. If you used a mental process sometimes or never in the assignment, judge it according to the averaged usage during the whole task.

1.Auditive emotional process

Requires the recognition of emotion (e.g. Tone or musical state of mind) presented by the hearing sense.

2.Auditive linguistical process

Requires the recognition of words, syllables of other verbal kinds of words whom are presented by the hearing sense.

3.Facefigure process

Requires the seeing and recognition of faces, or of the emotions that are shown on faces.

4.Face motivational process

Requires usage of your own facial muscles, independent from speech or expressing of feelings.

5.Manual process

Requires usage of motion of the arms, hands and/or fingers.

6.Short term memory process

Requires remembering of information during a periodic interval varying of a few seconds up till half a minute.

7.Spatial attentive process

Requires attention focused on a locatie, supported by the visual sense.

8.Spatial categorical process

Requires seeing simple left-vs-right or up-vs-down relationships, without taking the precise location into account.

9.Spatial concentration process

Requires seeing how close together various objects and forms are.

10.Spatial upcoming process

Requires the ‘picking’ of a form or object to see it from a messy or confusing background.

11.Spatial positional process

Requires the seeing and recognizing of a specific location as different from another location.

12.Spatial quantitative process

Requires seeing and judging of numerical entity based on a non-verbal, non-digital display. (e.g. barcharts or small clustered items).

13.Tactile figurative process

Requires feeling and recognizing or judging of forms (figures).

14.Visual lexical process
Requires the seeing and recognition of words, letters of numbers.

15.Visual fonetical process
Requires usage of detailistic analysis of the sound of words, letters or numbers that you see.

16.Visual temporal process
Requires judgement of time intervals, or from the timing of phenomena, supported by the sight sense.

17.Vocal process
Requires usage of your voice

Appendix 8 Translated MRQ comprehension check

Bijlage
The multiple resources questionnaire (MRQ) Rauwe vertaling

The multiple resources questionnaire
Het doel van deze vragenlijst is om de aard van de mentale processen te karakteriseren die worden gebruikt bij de taak waarmee u vertrouwd bent geraakt. Hieronder staan de namen en beschrijvingen van verschillende mentale processen. Lees ze zorgvuldig door, zodat u de aard van het proces begrijpt. Beoordeel vervolgens de taak op basis van de mate waarin het elk proces gebruikt, met behulp van de volgende schaal

Geen gebruik	Licht gebruik	Matig gebruik	Veel gebruik	Extreem gebruik

Belangrijk:
Aan alle onderdelen van de procesdefinitie moet worden voldaan om te kunnen beoordelen of deze is gebruikt. Het herkennen van visueel gepresenteerde geometrische figuren zou er bijvoorbeeld niet toe moeten leiden dat u oordeelt dat het 'Tactiele figuren' proces is gebruikt, alleen maar omdat er figuren bij betrokken waren. Om dat proces te kunnen gebruiken, moeten figuren tactiel worden verwerkt (d.w.z. met behulp van de tastzin).

Beoordeel de taak als geheel, gemiddeld over de tijd dat u hem hebt uitgevoerd. Als een bepaald proces op een bepaald punt in de taak is gebruikt en niet op een ander, moet uw beoordeling niet het 'piekgebruik' weerspiegelen, maar in plaats daarvan het gemiddelde gebruik over de gehele duur van de taak

Auditieve emotionele proces
Vereiste beoordelingen van emotie (bijv. Toon of muzikale stemming) gepresenteerd via het gehoor.

Auditieve taalkundige proces
Vereiste herkenning van woorden, lettergrepen of andere verbale woordsoorten die via het gehoor worden gepresenteerd.

Gezichtsfiguur proces
Vereiste herkenning van gezichten, of van de emoties die op gezichten worden getoond, gepresenteerd door het gevoel van zicht.

Gezicht motivatieel proces
Vereiste beweging van uw eigen gezichtsspieren, los van spraak of het uiten van emoties.

Handmatig proces
Vereiste beweging van de armen, handen en / of vingers.

Korte termijn geheugenproces
Vereist het onthouden van informatie gedurende een periode variërend van een paar seconden tot een halve minuut.

Ruimtelijk aandachtig proces
Vereiste aandacht richten op een locatie, met behulp van het zicht.

Ruimtelijk categorisch proces
Vereist oordeel over eenvoudige links-tegen-rechts of op-tegen-neer relaties, zonder rekening te houden met de precieze locatie, met behulp van het zicht.

Ruimtelijk concentratie proces
Vereist oordeel over hoe dicht bij elkaar talloze visuele objecten of vormen zijn.

Ruimtelijk opkomend proces
Vereist het 'uitkiezen' van een vorm of object uit een zeer rommelige of verwarrende achtergrond, met behulp van het zicht.

Ruimtelijk positioneel proces
Vereiste herkenning van een precieze locatie als verschillend van de andere locatie, met behulp van het zicht.

Ruimtelijk kwantitatief proces
Vereiste beoordeling van numerieke grootheid op basis van een non-verbale, niet-digitale weergave (bijvoorbeeld staafdiagrammen of kleine clusters van items), met behulp van het zicht.

Tactiel figuratief proces
Vereiste herkenning of beoordeling van vormen (figuren), met behulp van het tastzintuig.

Visueel lexicaal proces
Vereiste herkenning van woorden, letters of cijfers, met behulp van het zicht.

Visueel fonetisch proces
Vereiste gedetailleerde analyse van het geluid van woorden, letters of cijfers gepresenteerd met behulp van het zicht.

Visueel temporeel proces
Vereiste beoordeling van tijdsintervallen, of van de timing van gebeurtenissen, met behulp van het zicht.

Vocaal proces
Vereist gebruik van uw stem

Appendix 9 Test protocol

Introduction in Dutch

Fijn dat je wilt deelnemen aan dit onderzoek! Dit onderzoek wordt gedaan om te kijken naar de gebruiksvriendelijkheid on de online leeromgeving. Hiervoor ga jij informatie lezen over fotosynthese, een concept map maken in de online leeromgeving en vervolgens vul je een vragenlijst. Ook wordt er Eye Tracking apparatuur gebruikt.

Ik zal nu een korte toelichting geven over de online opdracht. Je krijgt eerst informatie over de lichtreactie van fotosynthese en daarna gaat je een concept map maken over de lichtreactie van fotosynthese. Ben je bekend met een concept map? Een concept map is vergelijkbaar met een mindmap. Het verschil is dat bij een mindmap je een centraal concept of begrip hebt terwijl je bij een concept map alle relaties tussen de concepten met elkaar verbindt. Hier heb ik een voorbeeld. Onthoud dat voor het onderzoek niks goed of fout is, er wordt alleen gekeken naar de gebruiksvriendelijkheid van de online leeromgeving.

Voordat je met de opdracht gaat beginnen gaan we eerste de Eye tracking apparatuur kalibreren. Dit gaat als volgt, er verschijnt zo een stip op het scherm, ik wil dat je naar het midden van deze stip kijkt en deze volgt op het scherm. Kijk alleen naar het beeldscherm. Als he kalibreren is gelukt gaat het programma automatisch naar de online leeromgeving. Hier kun je inloggen met een naam die ik jouw zo direct ga geven. Vervolgens kun je zelfstandig aan het werk. Ik zit hier alleen om te kijken of de apparatuur goed werkt.

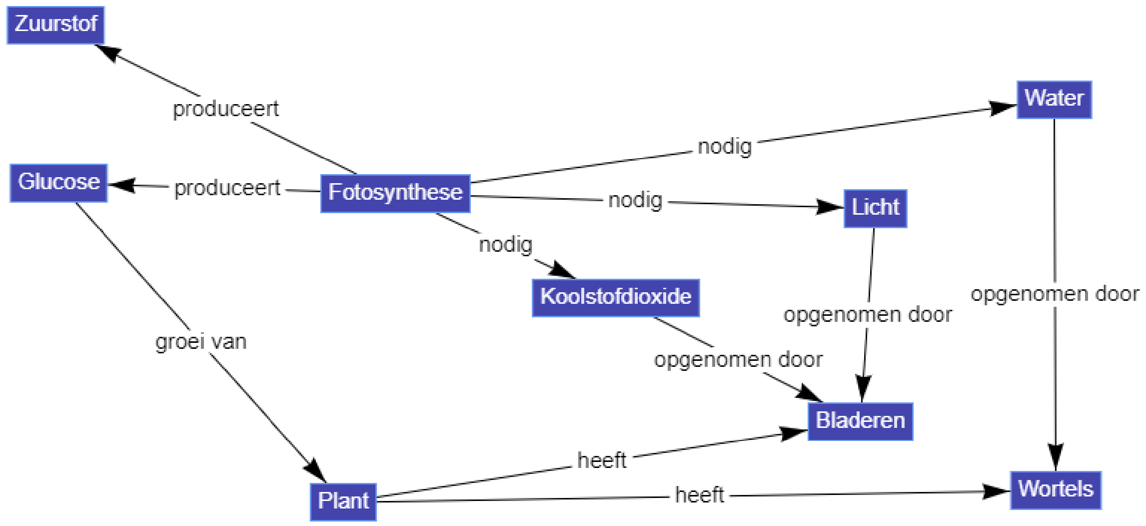
De eerste pagina van de online leeromgeving bevat informatie over het onderzoek, lees dit goed en vul de vragen onderin ook in! Dan pas mag je doorgaan naar de opdracht. Na de opdracht moet je nog een vragenlijst invullen en als je hiermee klaar bent mag je op de escape knop drukken.

Alle informatie die jij geeft blijft anoniem en allen ik en mijn begeleider kunnen deze inzien. Nadat het onderzoek volledig is afgerond worden alle gegevens verwijderd.

Heb je nu nog vragen?

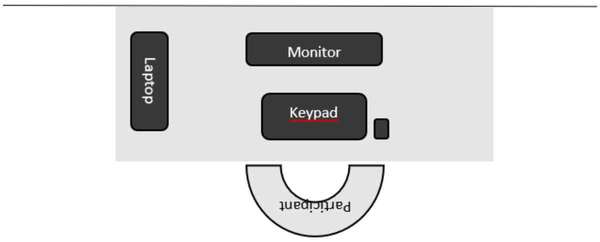
Jouw participant log in is ……… (Name the participant number assigned by the researcher)

Example Concept map in Dutch



Set-up

A table is set up against a plain wall, the participant will be facing the wall and before him there will be a monitor with a mouse and keypad before it. The laptop of the researcher containing the ET program will be place at the site so the screen is not visible for the participant.



Beforehand the calibration screen of the Eye Tracking equipment will be set-up by the researcher. After the calibration the online learning platform will pop-up automatically on log in screen. Participants are asked to fill in their participant id given to them beforehand. After that they can produce individually.

Set-up on screen

Tobii Pro Lab has to be activated in project one.
Set up until recorder
Already fill in the participant number
Already select participant group
Check if program is on screen recorder
Close all other tabs
Turn of volume

Estimated time duration

Greetings and short introduction :	10 minutes
Experimental task:	30 minutes
Minimum debriefing:	5 minutes
Overall:	45 minutes

Needed Equipment

Table

Two chairs

Laptop researcher

Tobii Pro Fusion Eye tracker

Monitor

Keypad

Computer mouse

Socket

Power strip

Example concept map

Participant ID’s for Go-Lab

Participants	Log-in ID	Group
1	Part1c	Control
2	Part2e	Experimental
3	Part3c	Control
4	Part4e	Experimental
5	Part5c	Control
6	Part6e	Experimental
7	Part7c	Control
8	Part8e	Experimental
9	Part9c	Control
10	Part10e	Experimental
11	Part11c	Control
12	Part12e	Experimental
13	Part13c	Control
14	Part14e	Experimental
15	Part15c	Control
16	Part16e	Experimental
17	Part17c	Control
18	Part18e	Experimental
19	Part19c	Control
20	Part20e	Experimental
21	Part21c	Control
22	Part22e	Experimental
23	Part23c	Control
24	Part24e	Experimental

Appendix 10 R script

Data Analysis

Mandy Wijenberg

1-3-2021

#Import data

```
library(readxl)

## Warning: package 'readxl' was built under R version 4.0.3

R_Data <- read_excel("Data/FinalData.xlsx")
# This participant did not fill in the consent question
R_Data <- filter(R_Data, Participants != 19)
R_Data
```

Participants	Group	Pcode	Sekse	Age	Ikhebeerdergewerk	Ikheboverfotosynt	Ikheboverdelichtr	Ikbenbekendmethet	Ikbengeinformeerd	Ikgeeftoestemming	Manualprocess	Shorttermmemorypr	Spatialattentivep	Spatialcategorica	Spatialconcentrativ	Spatialemergentpr	Spatialpositional	Tactilefiguralpro	Visuallexicalproc	ToT	TOT_SAC	CM_SAC	Totaldurationofwh	Numberofwholefixa	TotaldurationofCM	V_FBT	ClicksFB	ClicksCM

t	h	e	m	o	v	o	r	l	e	o	p	c	e	o	t	f
m	e	a	a	v	o	c	o	p	p	c	r	e	s	l	i	i
e	s	c	k	e	o	e	c	r	r	e	o	s	s	e	o	x
t	e	t	e	r	r	s	e	o	o	s	c	s		f	n	a
G	g	i	n	h	h	s	s	c	c	s	e			i	s	t
r	e	e	v	e	e		s	e	e		s			x		i
a	l	v	a	t	t			s	s		s			a		o
a	e	a	n	d	g			s	s					t		n
s	e	n	e	o	e									i		s
p	r	f	e	e	b									o		
	d	o	n	l	r									n		
	o	t	c	v	u									s		
	p	o	o	a	i											
	s	s	n	n	k											
	c	y	c	d	v											
	h	n	e	it	a											
	o	t	p	o	n											
	o	h	t	n	g											
	l	e	m	d	e											
		s	a	e	g											
		e	p	r	e											
		g		z	v											
		e		o	e											
		l		e	n											
		e		k	s											
		e			d											
		r			i											
		d			e											
		o			v											
		p			e											
		s			r											
		c			z											
		h			a											

							ool			meldwordentijdensditonderzoek																		
1	C	p1c	V	18	Nee	Ja	Ja	Ja	Ja	Ja	4	4	4	4	2	3	2	1	4	19.23	4385	1925	1348	5627	7423	4	0	84

																				9999999999998			036		02			
2	E	p2e	V	21	Nee	Ja	Nee	Nee	Ja	Ja	1	5	4	4	5	5	4	4	5	23.57	3612	1004	1278175	5194	512106	8	4	91
3	C	p3c	V	18	Nee	Ja	Ja	Nee	Ja	Ja	4	4	5	2	2	2	3	2	5	15.43	4833	1273	1463315	5450	532133	3	2	37
4	E	p4e	V	18	Nee	Ja	Ja	Nee	Ja	Ja	1	4	4	3	3	1	3	1	4	25.37	4941	1362	15070	6409	575153	0	1	101

																							44					
5	C	p5c	V	30	Nee	Ja	Ja	Ja	Ja	Ja	2	5	5	3	3	1	2	4	4	7.52	2395	668	932571	2722	320397	14	4	29
6	E	p6e	V	20	Nee	Ja	Ja	Ja	Ja	Ja	2	5	5	5	5	4	5	5	5	16.48	3089	790	1152875	3845	406265	0	0	54
7	C	p7c	V	21	Nee	Ja	Ja	Ja	Ja	Ja	3	5	5	1	4	1	2	2	5	41.42	6638	2796	2730249	8943	1589394	7	0	165
8	E	p8e	V	17	Nee	Ja	Ja	Ja	Ja	Ja	1	4	1	2	1	1	1	2	4	16.43	4126	933	1233847	4626	453421	0	9	63
9	C	p9c	V	25	Nee	Ja	Ja	Ja	Ja	Ja	4	5	5	4	2	1	3	1	5	24.	40	18	160	59	879	4	0	75

																				22	66	29	6064	63	955			
10	E	p10e	V	17	Nee	Ja	Ja	Nee	Ja	Ja	4	4	4	3	3	2	4	2	5	24.29	4568	1198	1535165	5382	639162	1	2	68
11	E	p11c	V	23	Nee	Ja	Ja	Nee	Ja	Ja	NA	4	3	1	1	1	2	3	4	19.21	4937	1289	1348814	5494	552021	4	2	73
12	C	p12c	V	20	Nee	Ja	Ja	Nee	Ja	Ja	4	5	4	4	5	3	5	4	4	23.02	4604	1789	1576591	7207	776492	1	1	71
13	E	p13e	M	19	Nee	Ja	Ja	Ja	Ja	Ja	3	1	4	2	1	1	1	1	4	23.26	3441	855	1353513	5095	609948	2	0	116

14	C	p14c	M	24	Nee	Ja	Nee	Nee	Ja	Ja	4	4	5	3	1	3	NA	4	4	18.489999999999998	3969	985	1526149	6194	557145	1	2	104
15	C	p15c	V	18	Nee	Ja	Ja	Nee	Ja	Ja	4	5	3	2	1	2	1	1	5	25	3913	1035	1344218	7933	572265	5	0	89
16	E	p16e	V	22	Nee	Ja	Ja	Ja	Ja	Ja	2	4	1	4	2	1	1	2	5	17.1700000	2191	311	853086	4558	186288	0	2	26

																				00000002								
17	C	p17c	M	20	Ja	Ja	Ja	Ja	Ja	Ja	3	4	4	3	4	3	3	1	5	22.53	6574	2621	1840010	7389	887965	8	0	150
18	E	p18e	M	19	Nee	Ja	Ja	Nee	Ja	Ja	5	5	5	1	1	1	1	1	5	19.39	3993	1073	1317257	4519	605577	0	0	92
20	E	p20e	M	21	Ja	Ja	Nee	Nee	Ja	Ja	4	3	5	1	1	1	1	1	5	25	5756	1234	1550533	6408	509526	0	3	63
21	C	p21c	M	18	Nee	Ja	Ja	Ja	Ja	Ja	2	5	3	4	4	4	3	3	4	10.37	3278	799	1084	3559	3825	0	0	33

																							964		68			
22	E	p22e	V	18	Nee	Ja	Ja	Ja	Ja	Ja	5	4	5	3	1	1	3	4	5	42.32	7572	1721	2121885	10114	743838	3	0	153
23	C	p23c	V	19	Nee	Ja	Ja	Ja	Ja	Ja	4	5	4	4	3	1	3	1	5	36.340000000000003	6706	3048	2397955	9017	1473840	26	0	158
24	E	p24e	V	18	Nee	Ja	Ja	Ja	Ja	Ja	4	4	5	2	2	3	3	2	5	24.44	5241	1803	154961	6226	8164887	4	0	122

3
7

Geografic data

```
R_Data %>%
 group_by(Group)%>%
 summarise(MEAN_Age = mean(Age))
```

Group	MEAN_Age
C	21.00000
E	19.41667

Cronbach Alpha

To argue that the combined item form the questionnaire measure the same thing

```
library(psych)

## Warning: package 'psych' was built under R version 4.0.4

##
## Attaching package: 'psych'

## The following objects are masked from 'package:ggplot2':
##
##     %+%, alpha

alpha(R_Data[,c("Manual process", "Short term memory process", "Spatial attentive process", "Spatial categorical process", "Spatial concentrative process", "Spatial emergent process", "Spatial positional process", "Tactile figural process", "Visual lexical process")])

## Warning in alpha(R_Data[, c("Manual process", "Short term memory process", : Some items were negatively correlated with the total scale and probably
## should be reversed.
## To do this, run the function again with the 'check.keys=TRUE' option

## Some items ( Manual process ) were negatively correlated with the total scale and
## probably should be reversed.
## To do this, run the function again with the 'check.keys=TRUE' option
```

```
##
## Reliability analysis
## Call: alpha(x = R_Data[, c("Manual process", "Short term memory process",
## "Spatial attentive process", "Spatial categorical process",
## "Spatial concentrative process", "Spatial emergent process",
## "Spatial positional process", "Tactile figural process",
## "Visual lexical process")])
##
## raw_alpha std.alpha G6(smc) average_r S/N ase mean sd median_r
## 0.73 0.72 0.84 0.23 2.6 0.078 3.1 0.67 0.27
##
## lower alpha upper 95% confidence boundaries
## 0.58 0.73 0.89
##
## Reliability if an item is dropped:
## raw_alpha std.alpha G6(smc) average_r S/N
## Manual process 0.80 0.78 0.83 0.30 3.5
## Short term memory process 0.70 0.69 0.82 0.22 2.2
## Spatial attentive process 0.73 0.71 0.82 0.24 2.5
## Spatial categorical process 0.69 0.69 0.81 0.22 2.2
## Spatial concentrative process 0.67 0.66 0.76 0.20 1.9
## Spatial emergent process 0.68 0.67 0.81 0.20 2.1
## Spatial positional process 0.62 0.62 0.75 0.17 1.6
## Tactile figural process 0.70 0.70 0.81 0.22 2.3
## Visual lexical process 0.74 0.74 0.85 0.26 2.8
## alpha se var.r med.r
## Manual process 0.055 0.062 0.33
## Short term memory process 0.088 0.109 0.20
## Spatial attentive process 0.075 0.107 0.33
## Spatial categorical process 0.092 0.086 0.25
## Spatial concentrative process 0.102 0.074 0.25
## Spatial emergent process 0.098 0.090 0.25
## Spatial positional process 0.117 0.081 0.19
## Tactile figural process 0.091 0.094 0.25
## Visual lexical process 0.079 0.103 0.34
##
## Item statistics
```

```
##                                  n raw.r std.r r.cor r.drop mean   sd
## Manual process                  22 0.073  0.12 0.054  -0.14  3.2 1.26
## Short term memory process       23 0.569  0.61 0.533   0.46  4.3 0.92
## Spatial attentive process       23 0.472  0.49 0.418   0.29  4.0 1.19
## Spatial categorical process     23 0.642  0.61 0.562   0.49  2.8 1.19
## Spatial concentrative process   23 0.745  0.72 0.750   0.61  2.5 1.44
## Spatial emergent process        23 0.714  0.67 0.620   0.58  2.0 1.24
## Spatial positional process      22 0.893  0.88 0.919   0.86  2.5 1.26
## Tactile figural process         23 0.626  0.57 0.513   0.46  2.3 1.32
## Visual lexical process          23 0.228  0.36 0.229   0.15  4.6 0.50
##
## Non missing response frequency for each item
##                                  1    2    3    4    5 miss
## Manual process                0.14 0.18 0.14 0.45 0.09 0.04
## Short term memory process     0.04 0.00 0.04 0.48 0.43 0.00
## Spatial attentive process     0.09 0.00 0.13 0.35 0.43 0.00
## Spatial categorical process   0.17 0.22 0.26 0.30 0.04 0.00
## Spatial concentrative process 0.35 0.22 0.17 0.13 0.13 0.00
## Spatial emergent process      0.52 0.13 0.22 0.09 0.04 0.00
## Spatial positional process    0.27 0.18 0.36 0.09 0.09 0.04
## Tactile figural process       0.39 0.26 0.09 0.22 0.04 0.00
## Visual lexical process        0.00 0.00 0.00 0.39 0.61 0.00
```

Manual processing can be remove, because this is the only question that asks about a physical functioning while other question are about cognitive functioning.

Constructing one scale of mulitple items

```
library(dplyr)
R_Data <- R_Data %>%
  rowwise() %>%
  mutate(sub.cl = mean(c(`Short term memory process`, `Spatial attentive process`, `Spatial categorical process`, `Spatial concentrative process`, `Spatial emergent process`, `Spatial positional process`, `Tactile figural process`, `Visual lexical process`), na.rm = TRUE ))

select(R_Data, Participants, Group, sub.cl) # DIT DOET HET NIET MEER, WHY?
```

```
## # A tibble: 23 x 3
## # Rowwise:
##    Participants Group sub.cl
##           <dbl> <chr>  <dbl>
##  1            1 C       3
##  2            2 E       4.5
##  3            3 C       3.12
##  4            4 E       2.88
##  5            5 C       3.38
##  6            6 E       4.88
##  7            7 C       3.12
##  8            8 E       2
##  9            9 C       3.25
## 10           10 E       3.38
## # ... with 13 more rows
```

Constructing final variables for objective cogntive load and engagement level

```
R_Data <-
 mutate(R_Data, across(c(CM_SAC, `Total duration of CM fixations`, ToT, V_FBT), as.numeric ))

R_Data <-
 mutate(R_Data,
        ob.cl = CM_SAC/ ToT,
        en.lvl = `Total duration of CM fixations`/ `Total duration of whole fixations`* 100)
```

summary tabel of Variables

```
R_Data %>%
 group_by(Group) %>%
 summarise(mean_sub.cl = mean(sub.cl,na.rm = TRUE),
       mean_ob.cl = mean(ob.cl),
       mean_en.lvl = mean(en.lvl),
       mean_c.fbt = mean(`Clicks FB`, na.rm = TRUE)) %>%
 print()

## # A tibble: 2 x 5
##   Group mean_sub.cl mean_ob.cl mean_en.lvl mean_c.fbt
```

```
## * <chr> <dbl> <dbl> <dbl> <dbl>
## 1 C 3.31 78.5 46.6 0.818
## 2 E 2.97 49.3 38.9 1.92
```

Visualazing data –> DEZE DOET NIET MEER WHY?

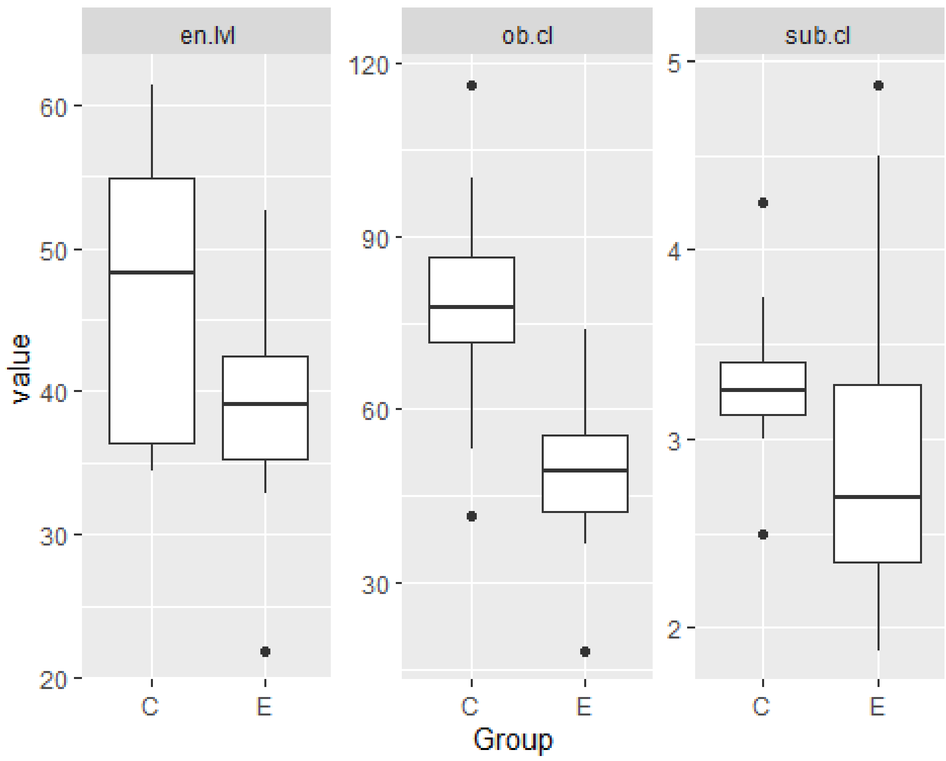
```
data_long <- pivot_longer(R_Data, c( sub.cl, ob.cl, en.lvl ), names_to = "outcome" )
data_long %>% select(outcome, value, Participants)
```

outcome	value	Participants
sub.cl	3.000000	1
ob.cl	100.051975	1
en.lvl	55.065443	1
sub.cl	4.500000	2
ob.cl	42.596521	2
en.lvl	40.065406	2
sub.cl	3.125000	3
ob.cl	82.501620	3
en.lvl	36.364897	3
sub.cl	2.875000	4
ob.cl	53.685455	4
en.lvl	38.164314	4
sub.cl	3.375000	5
ob.cl	88.829787	5
en.lvl	34.356312	5
sub.cl	4.875000	6
ob.cl	47.936893	6
en.lvl	35.239293	6
sub.cl	3.125000	7
ob.cl	67.503621	7
en.lvl	58.214251	7

sub.cl	2.000000	8
ob.cl	56.786366	8
en.lvl	36.748560	8
sub.cl	3.250000	9
ob.cl	75.516102	9
en.lvl	54.789535	9
sub.cl	3.375000	10
ob.cl	49.320708	10
en.lvl	41.634743	10
sub.cl	2.375000	11
ob.cl	67.100469	11
en.lvl	40.926399	11
sub.cl	4.250000	12
ob.cl	77.715030	12
en.lvl	49.251328	12
sub.cl	1.875000	13
ob.cl	36.758384	13
en.lvl	45.064067	13
sub.cl	3.428571	14
ob.cl	53.272039	14
en.lvl	36.506593	14
sub.cl	2.500000	15
ob.cl	41.400000	15
en.lvl	42.572336	15
sub.cl	2.500000	16
ob.cl	18.112988	16
en.lvl	21.836954	16
sub.cl	3.375000	17

ob.cl	116.333777	17
en.lvl	48.258705	17
sub.cl	2.500000	18
ob.cl	55.337803	18
en.lvl	45.972578	18
sub.cl	2.250000	20
ob.cl	49.360000	20
en.lvl	32.861345	20
sub.cl	3.750000	21
ob.cl	77.049180	21
en.lvl	35.260893	21
sub.cl	3.250000	22
ob.cl	40.666352	22
en.lvl	35.055529	22
sub.cl	3.250000	23
ob.cl	83.874518	23
en.lvl	61.462371	23
sub.cl	3.250000	24
ob.cl	73.772504	24
en.lvl	52.688920	24

```
ggplot(data_long, aes( x = Group, y = value ) ) +
 geom_boxplot() +
  facet_wrap( vars(outcome), ncol = 10, scales = "free_y" )
```



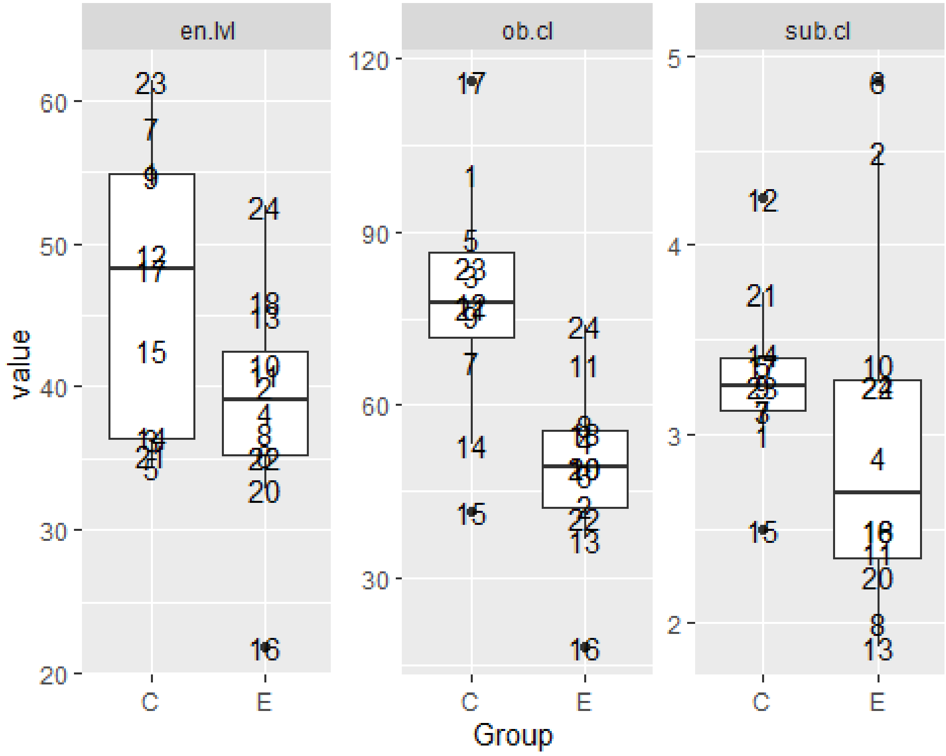

```
data_long %>% select( outcome, value, Participants)
```

outcome	value	Participants
sub.cl	3.000000	1
ob.cl	100.051975	1
en.lvl	55.065443	1
sub.cl	4.500000	2
ob.cl	42.596521	2
en.lvl	40.065406	2
sub.cl	3.125000	3
ob.cl	82.501620	3
en.lvl	36.364897	3
sub.cl	2.875000	4
ob.cl	53.685455	4
en.lvl	38.164314	4
sub.cl	3.375000	5

ob.cl	88.829787	5
en.lvl	34.356312	5
sub.cl	4.875000	6
ob.cl	47.936893	6
en.lvl	35.239293	6
sub.cl	3.125000	7
ob.cl	67.503621	7
en.lvl	58.214251	7
sub.cl	2.000000	8
ob.cl	56.786366	8
en.lvl	36.748560	8
sub.cl	3.250000	9
ob.cl	75.516102	9
en.lvl	54.789535	9
sub.cl	3.375000	10
ob.cl	49.320708	10
en.lvl	41.634743	10
sub.cl	2.375000	11
ob.cl	67.100469	11
en.lvl	40.926399	11
sub.cl	4.250000	12
ob.cl	77.715030	12
en.lvl	49.251328	12
sub.cl	1.875000	13
ob.cl	36.758384	13
en.lvl	45.064067	13
sub.cl	3.428571	14
ob.cl	53.272039	14

en.lvl	36.506593	14
sub.cl	2.500000	15
ob.cl	41.400000	15
en.lvl	42.572336	15
sub.cl	2.500000	16
ob.cl	18.112988	16
en.lvl	21.836954	16
sub.cl	3.375000	17
ob.cl	116.333777	17
en.lvl	48.258705	17
sub.cl	2.500000	18
ob.cl	55.337803	18
en.lvl	45.972578	18
sub.cl	2.250000	20
ob.cl	49.360000	20
en.lvl	32.861345	20
sub.cl	3.750000	21
ob.cl	77.049180	21
en.lvl	35.260893	21
sub.cl	3.250000	22
ob.cl	40.666352	22
en.lvl	35.055529	22
sub.cl	3.250000	23
ob.cl	83.874518	23
en.lvl	61.462371	23
sub.cl	3.250000	24
ob.cl	73.772504	24
en.lvl	52.688920	24

```
ggplot(data_long, aes( x = Group, y = value ) ) +
 geom_boxplot() +
 geom_text(aes(label=Participants)) +
 facet_wrap( vars(outcome), ncol = 10, scales = "free_y" )
```



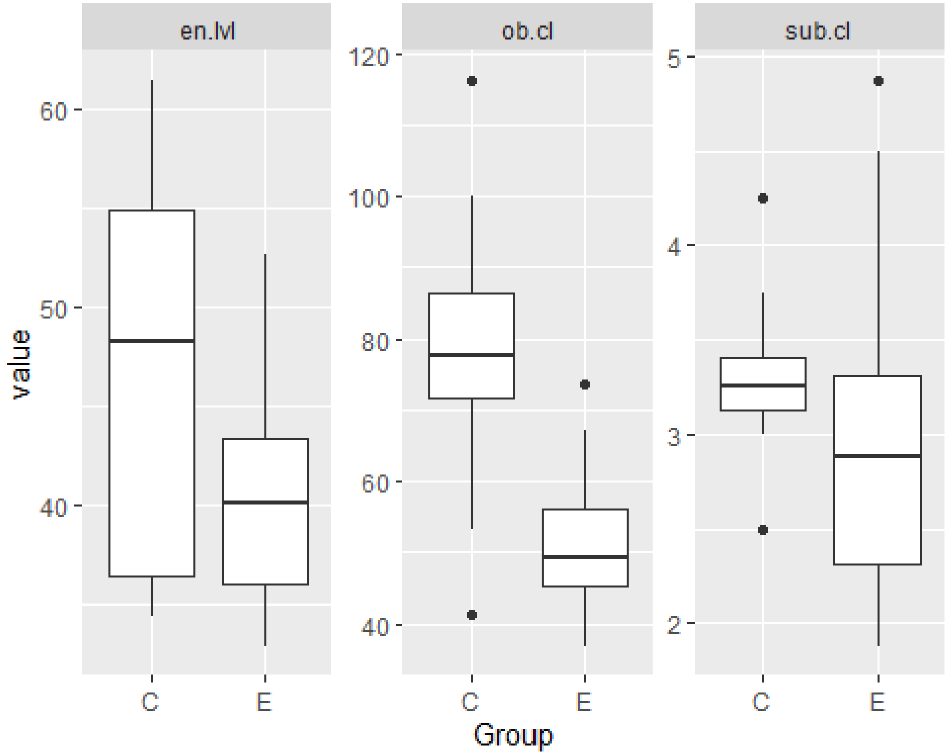
Participant 16 stood out in two scale, so checked the notes from the experiment, this participant had glasses with -3,5 on both sides. This could have effected the measuring with the Eye Tracking. So therefore it was chosen to remove this participant from the data.

Removing participant 16

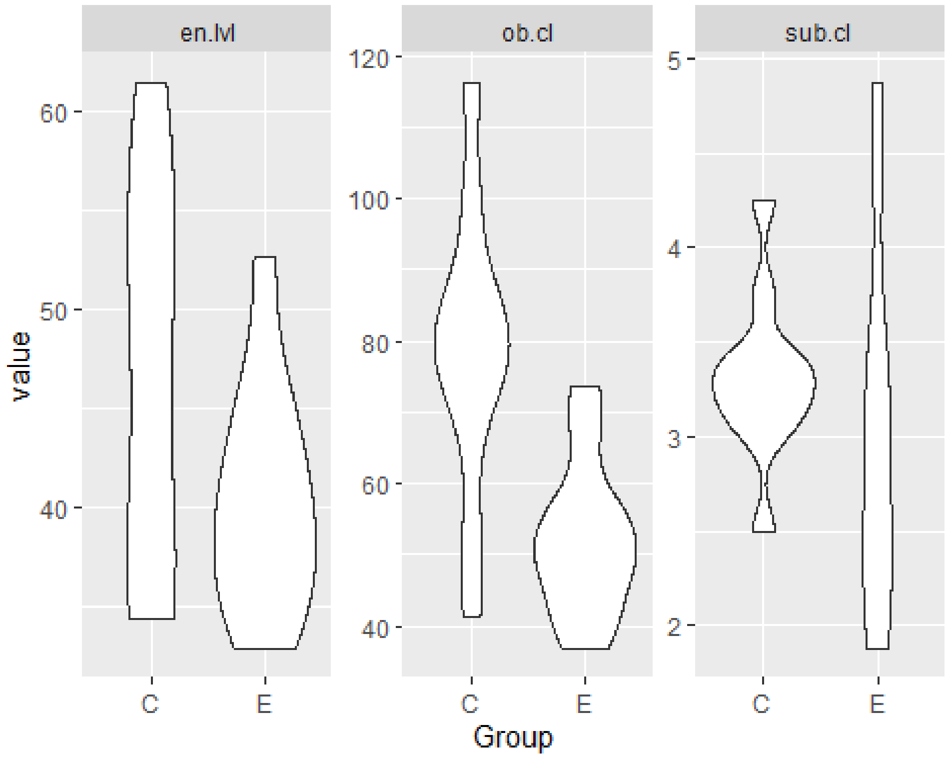
```
R_Data <- filter(R_Data, Participants != 16)
data_long <- pivot_longer(R_Data, c( sub.cl, ob.cl, en.lvl), names_to = "outcome" )
```

Checking data again for abnormalities

```
ggplot(data_long, aes( x = Group, y = value ) ) +
 geom_boxplot() +
 facet_wrap( vars(outcome), ncol = 10, scales = "free_y" )
```




```
ggplot(data_long, aes(x = Group, y = value)) +
  geom_violin() +
  facet_wrap( vars(outcome), ncol = 10, scales = "free_y" )
```

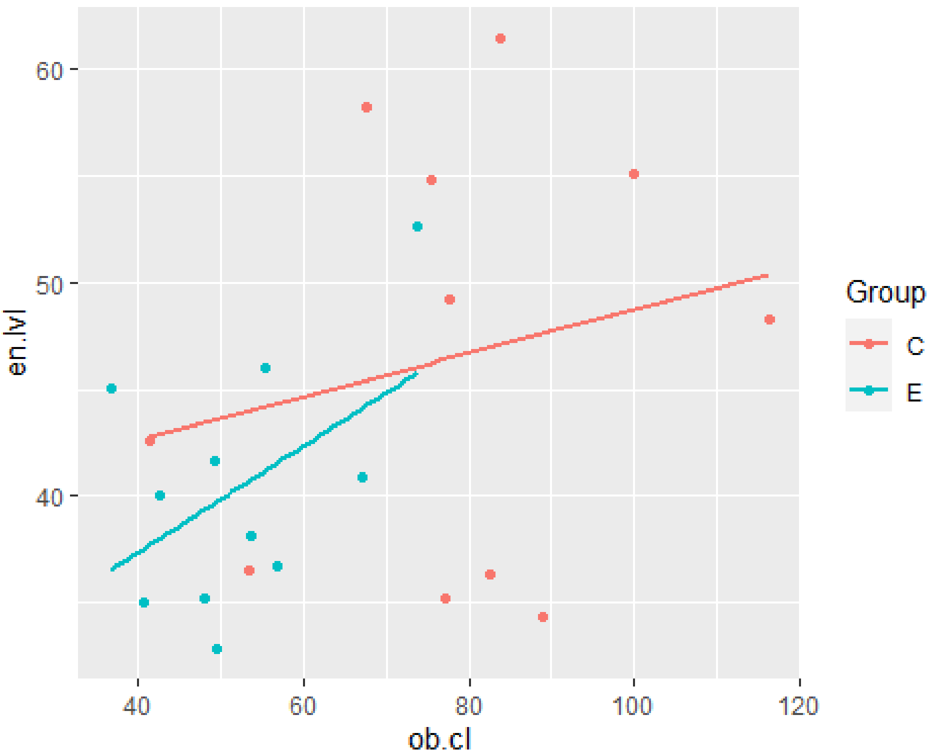


Other outliers had no signs of abnormalities while testing, so they were not removed from the data.

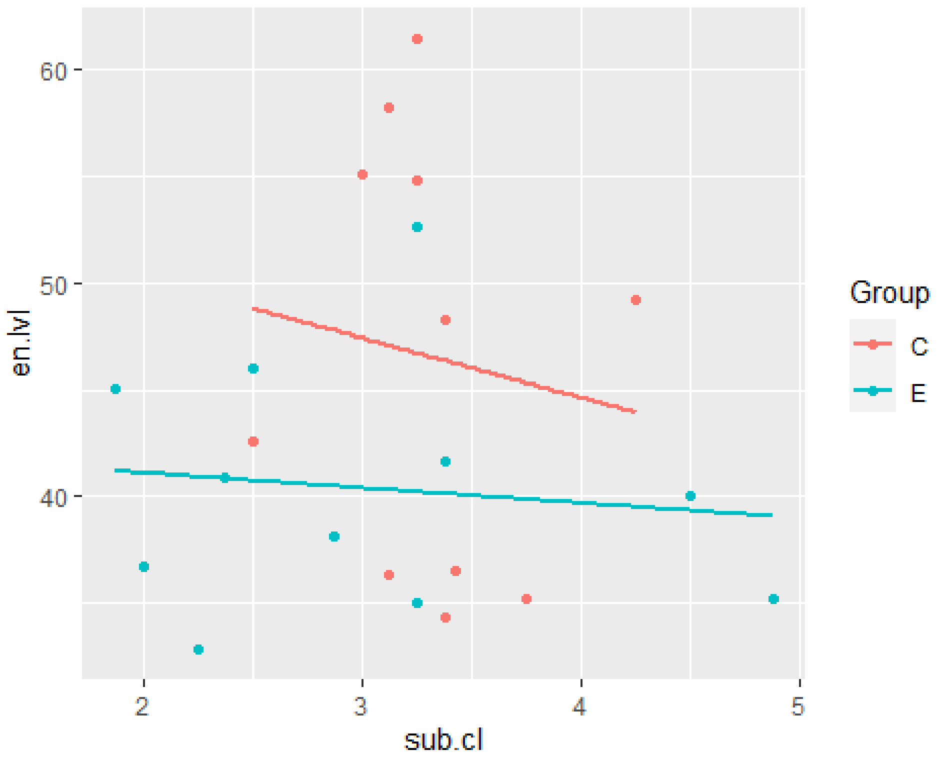
Checking assumptions for the Manova

1. Linearity of dependent variables Check
2. Normal distribution of the dependent variables Check
3. Multivariate homogeneity of variance within groups and between groups Check

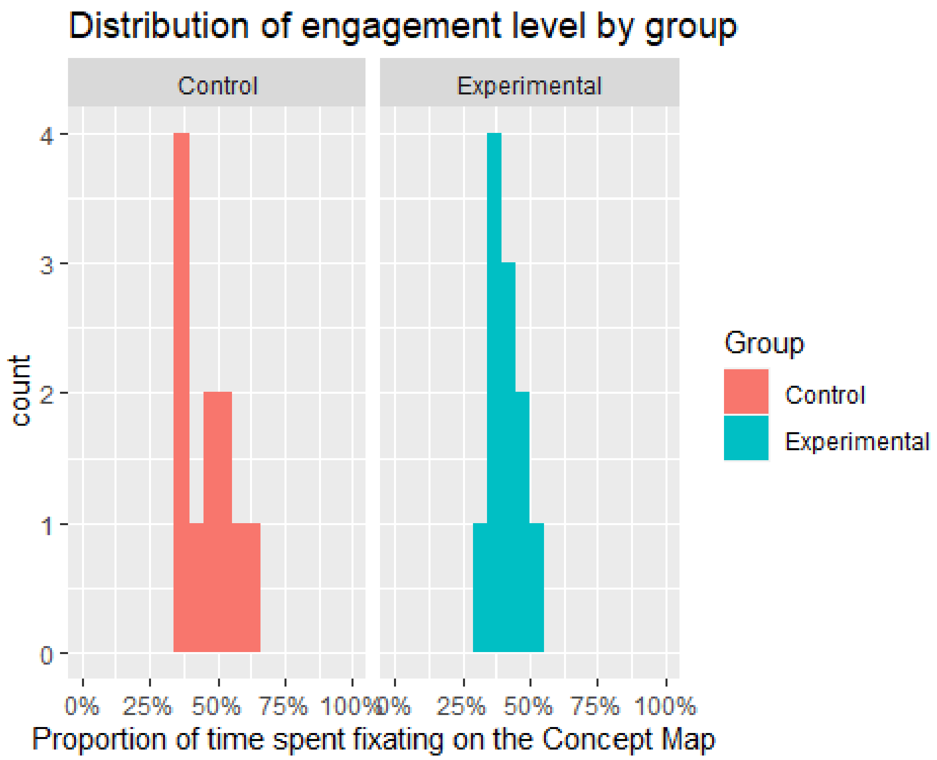
```
library(ggplot2)
#1
ggplot(R_Data, aes( x =ob.cl, y=en.lvl, color =Group)) + geom_point() + geom_smooth(method="lm
", se=FALSE)

## `geom_smooth()` using formula 'y ~ x'
```



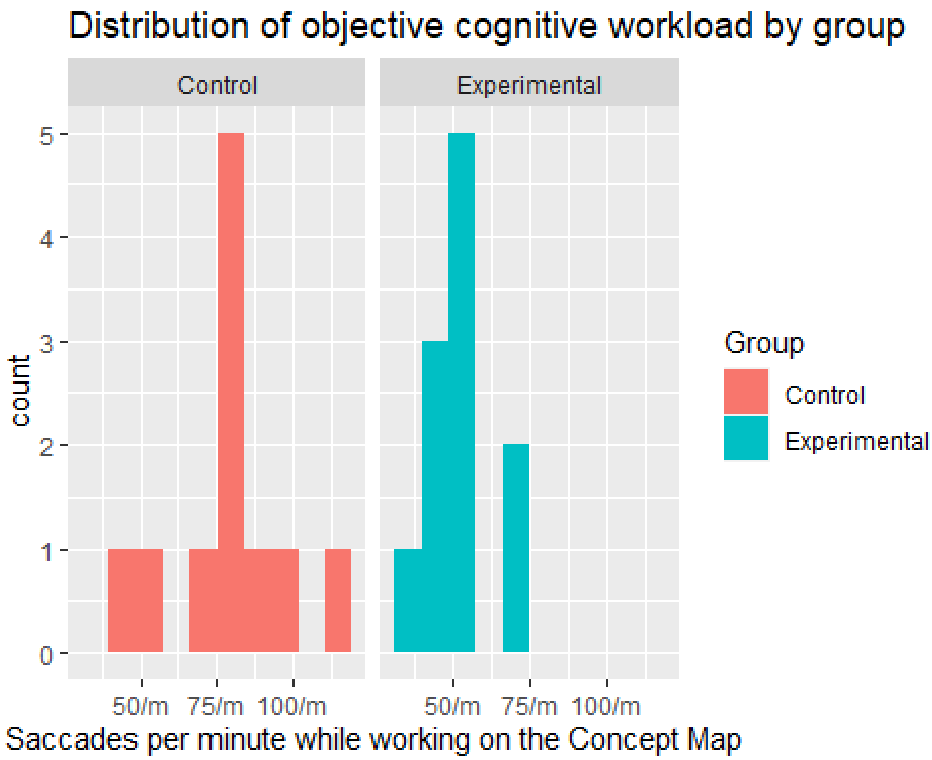

```
ggplot(R_Data, aes( x =sub.cl, y=en.lvl, color =Group)) + geom_point() + geom_smooth(method="l
m", se=FALSE)

## `geom_smooth()` using formula 'y ~ x'
```



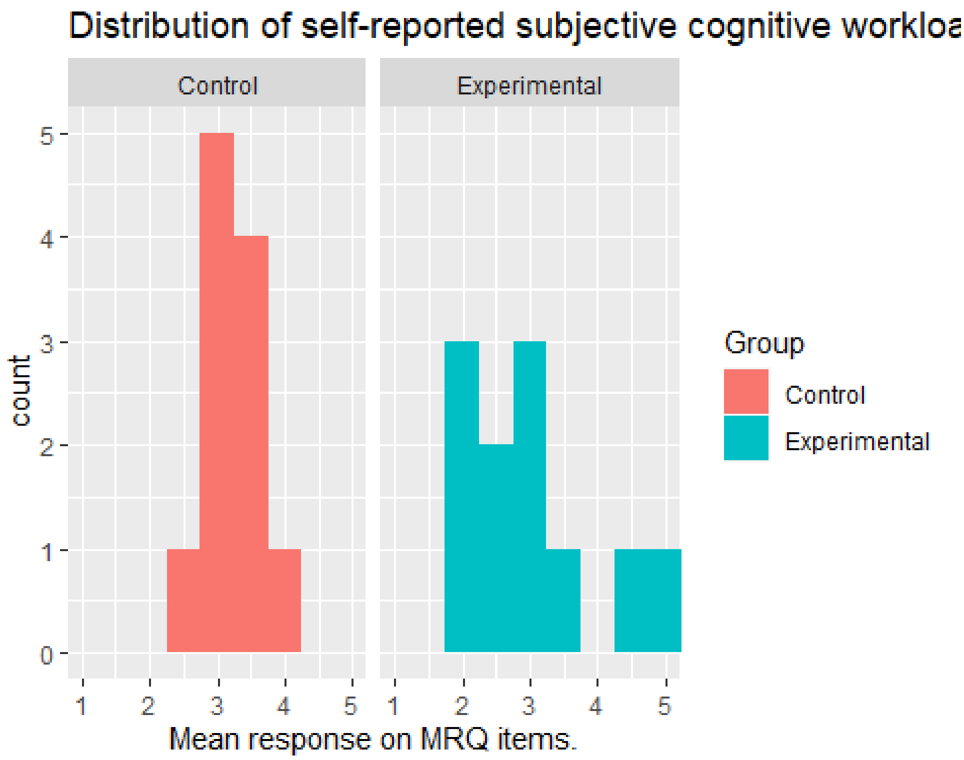

```
#2

data_long <- mutate(data_long,
    Group = recode(Group,
        E = "Experimental",
        C = "Control"))

R_Data <- mutate(R_Data, Group = recode( Group, E = "Experimental", C = "Control"))

ggplot(data_long %>% filter( outcome == "en.lvl" ), aes( x = value, fill = Group ) ) +
  geom_histogram( aes( x = value / 100 ), bins = 20 ) +
  facet_wrap( ~Group, scales = "fixed" ) +
  scale_x_continuous(labels = scales::label_percent(), limits = c(0,1) ) +
  labs( title="Distribution of engagement level by group",
     x = "Proportion of time spent fixating on the Concept Map")

## Warning: Removed 4 rows containing missing values (geom_bar).
```




```r
ggplot(data_long %>% filter( outcome == "ob.cl" ), aes( x = value, fill = Group ) ) +
 geom_histogram( bins = 10 ) +
 facet_wrap( ~Group, scales = "fixed" ) +
 scale_x_continuous( labels = function( x ) paste0(x, "/m")) +
 labs( title="Distribution of objective cognitive workload by group",
     x = "Saccades per minute while working on the Concept Map" )
```




```
ggplot(data_long %>% filter( outcome == "sub.cl" ), aes( x = value, fill = Group ) ) +
 geom_histogram( binwidth = 0.5 ) +
 facet_wrap( ~Group, scales = "fixed" ) +
 coord_cartesian( xlim = c(1,5))+
 labs( title="Distribution of self-reported subjective cognitive workload by group",
     x = "Mean response on MRQ items.")
```




```
#2 additional check
shapiro.test(R_Data$sub.cl)

##
## Shapiro-Wilk normality test
##
## data: R_Data$sub.cl
## W = 0.94958, p-value = 0.3099

shapiro.test(R_Data$ob.cl)

##
## Shapiro-Wilk normality test
##
## data: R_Data$ob.cl
## W = 0.94252, p-value = 0.2231

shapiro.test(R_Data$sub.cl)

##
## Shapiro-Wilk normality test
##
```

```
## data: R_Data$sub.cl
## W = 0.94958, p-value = 0.3099
```

The Shapiro-Wilk Test of all dependent variables shows no significant, meaning that the data is normally distributed.

```
#3
#install.packages("rstatix")
library(rstatix)

## Warning: package 'rstatix' was built under R version 4.0.4

##
## Attaching package: 'rstatix'

## The following object is masked from 'package:stats':
##
## filter

box_m(R_Data %>% select(en.lvl, ob.cl, sub.cl), R_Data$Group)
```

statistic	p.value	parameter	method
12.38891	0.0538343	6	Box’s M-test for Homogeneity of Covariance Matrices

The data provides no reason to assume that the assumptions of Manova are deviant. Therefore a Manova will be performed.

Checking for significance via Manova

```
library(dplyr)
result = manova(cbind(sub.cl, ob.cl, en.lvl)~ Group, data = R_Data)

summary(result)

## Df Pillai approx F num Df den Df Pr(>F)
## Group 1 0.43912 4.6975 3 18 0.01361 *
## Residuals 20
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

coef(result)
```

	sub.cl	ob.cl	en.lvl
(Intercept)	3.3116883	78.54979	46.554788
GroupExperimental	-0.3003247	-26.42965	-6.152865

The P value is 0.01361, which mean that the H0 can be disregarded for at least one of the variables.

H0 = There is no difference between groups in cognitive workload.

Discriminant function analyses

```
library(MASS)

##
## Attaching package: 'MASS'

## The following object is masked from 'package:rstatix':
##
##     select

## The following object is masked from 'package:dplyr':
##
##     select

dfa <- lda(Group~ en.lvl + ob.cl + sub.cl, R_Data)

predictions <- dfa %>% predict(R_Data)

head(predictions$posterior, 22)
```

Control	Experimental
0.9737349	0.0262651
0.1794549	0.8205451
0.7688046	0.2311954
0.1886047	0.8113953
0.8596264	0.1403736
0.2560523	0.7439477

0.7057469	0.2942531
0.1537850	0.8462150
0.8183859	0.1816141
0.1934491	0.8065509
0.4074605	0.5925395
0.8775144	0.1224856
0.0393734	0.9606266
0.2169128	0.7830872
0.0715968	0.9284032
0.9930722	0.0069278
0.2428625	0.7571375
0.0808140	0.9191860
0.7278149	0.2721851
0.0697850	0.9302150
0.9295304	0.0704696
0.7769304	0.2230696

```
mean(predictions$class==R_Data$Group)

## [1] 0.8636364
```

Checking individual varibales separate on significance

```
r_sub.cl = aov(sub.cl ~ Group, data = R_Data)
summary(r_sub.cl)

##             Df Sum Sq Mean Sq F value Pr(>F)
## Group        1  0.496  0.4961   0.867  0.363
## Residuals   20 11.442  0.5721

coef(r_sub.cl)

##        (Intercept) GroupExperimental
##          3.3116883        -0.3003247
```

When independent the variable subjective cognitive workload is not significant

```
r_ob.cl = aov(ob.cl ~ Group, data = R_Data)
summary(r_ob.cl)

##             Df Sum Sq Mean Sq F value  Pr(>F)
## Group        1   3842    3842    14.2 0.00121 **
## Residuals   20   5412     271
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

coef(r_ob.cl)

##        (Intercept) GroupExperimental
##         78.54979         -26.42965
```

When independent, the variable objective cognitive workload is still significant. It has a p-value of 0,00121. After the intercept of 78,55 the experimental group has 26,43 less saccades per minute.

```
r_en.lvl = aov(en.lvl ~ Group, data = R_Data)
summary(r_en.lvl)

##             Df Sum Sq Mean Sq F value Pr(>F)
## Group        1  208.2  208.22   3.104 0.0934 .
## Residuals   20 1341.7   67.09
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

coef(r_en.lvl)

##        (Intercept) GroupExperimental
##         46.554788         -6.152865
```

When independent the variable engagement level is not significant

```
# install.packages("mlmRev")
library(lme4)

## Warning: package 'lme4' was built under R version 4.0.4

## Loading required package: Matrix

##
## Attaching package: 'Matrix'
```

```
## The following objects are masked from 'package:tidyr':
##
##     expand, pack, unpack
```

```
## Registered S3 methods overwritten by 'lme4':
## method from
## cooks.distance.influence.merMod car
## influence.merMod car
## dfbeta.influence.merMod car
## dfbetas.influence.merMod car
```

```
library(mlmRev)
```

```
## Warning: package 'mlmRev' was built under R version 4.0.5
```

```
#install.packages("sjPlot")
#install.packages("glmmTMB")
library(sjPlot)
```

```
## Warning: package 'sjPlot' was built under R version 4.0.5
```

```
## Install package "strengejacke" from GitHub (`devtools::install_github("strengejacke/strengejacke")`
) to load all sj-packages at once!
```

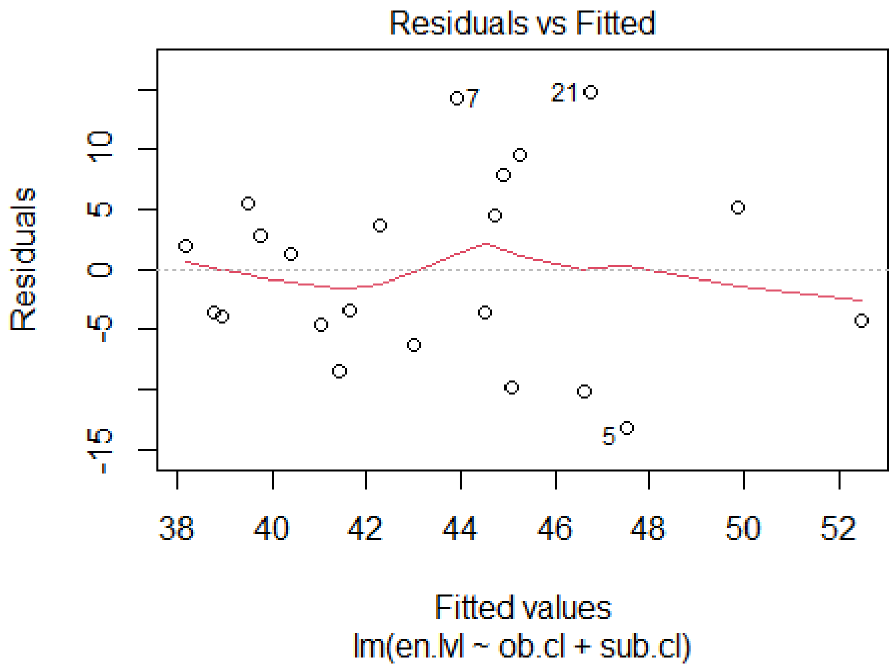
```
library(glmmTMB)
```

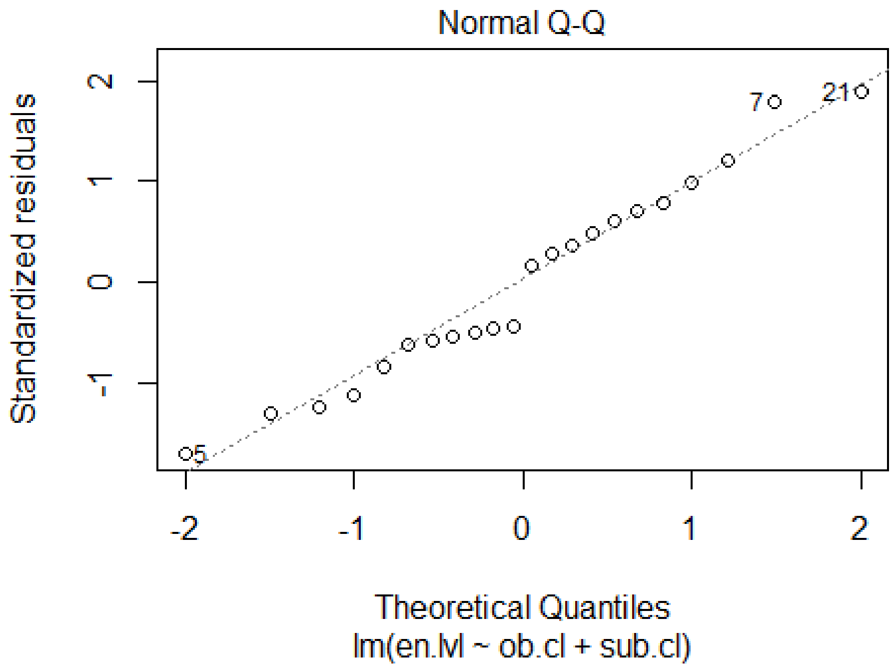
```
## Warning: package 'glmmTMB' was built under R version 4.0.5
```

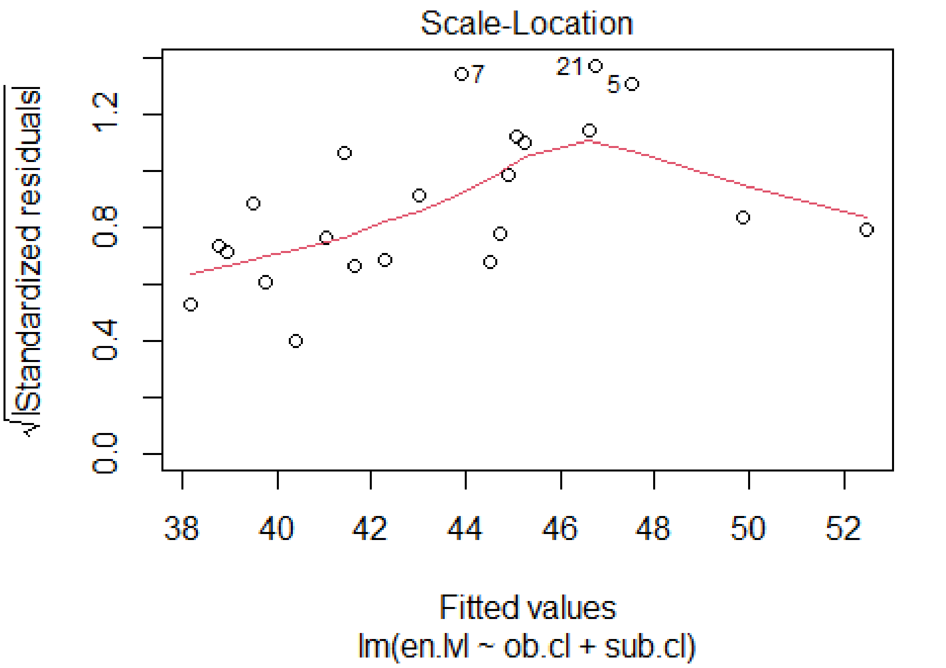
```
## Warning in checkMatrixPackageVersion(): Package version inconsistency detected.
## TMB was built with Matrix version 1.3.2
## Current Matrix version is 1.2.18
## Please re-install 'TMB' from source using install.packages('TMB', type = 'source') or ask CRAN for
a binary version of 'TMB' matching CRAN's 'Matrix' package
```

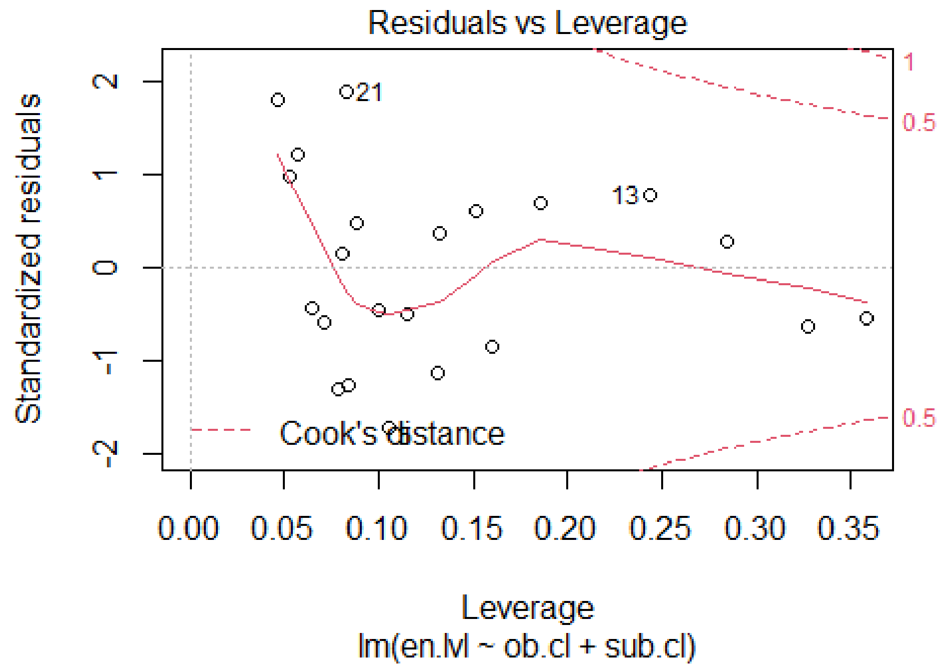
Checking linear relationship for the overall group

```
lm2 <- lm(en.lvl ~ ob.cl + sub.cl, R_Data )
plot(lm2)
```


Residuals vs Fitted
Residuals
Fitted values
lm(en.lvl ~ ob.cl + sub.cl)
7
21
5
-15
-5
0
5
10
38
40
42
44
46
48
50
52


Normal Q-Q
Standardized residuals
Theoretical Quantiles
lm(en.lvl ~ ob.cl + sub.cl)
7
21
5
-1
0
1
2
-2
-1
0
1
2





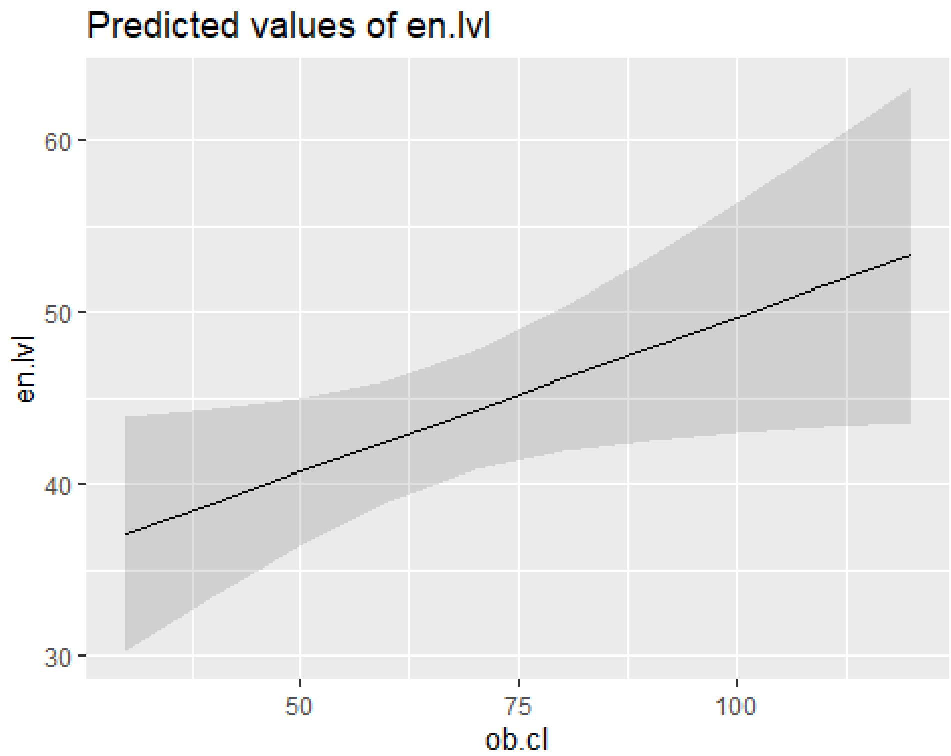

```
summary(lm2)

##
## Call:
## lm(formula = en.lvl ~ ob.cl + sub.cl, data = R_Data)
```

```
##
## Residuals:
## Min 1Q Median 3Q Max
## -13.159 -4.468 -1.120 5.023 14.725
##
## Coefficients:
## Estimate Std. Error t value Pr(>|t|)
## (Intercept) 34.60782 8.84420 3.913 0.000935 ***
## ob.cl 0.18016 0.08549 2.107 0.048589 *
## sub.cl -0.91741 2.38008 -0.385 0.704183
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 8.131 on 19 degrees of freedom
## Multiple R-squared: 0.1896, Adjusted R-squared: 0.1043
## F-statistic: 2.223 on 2 and 19 DF,  p-value: 0.1357
```

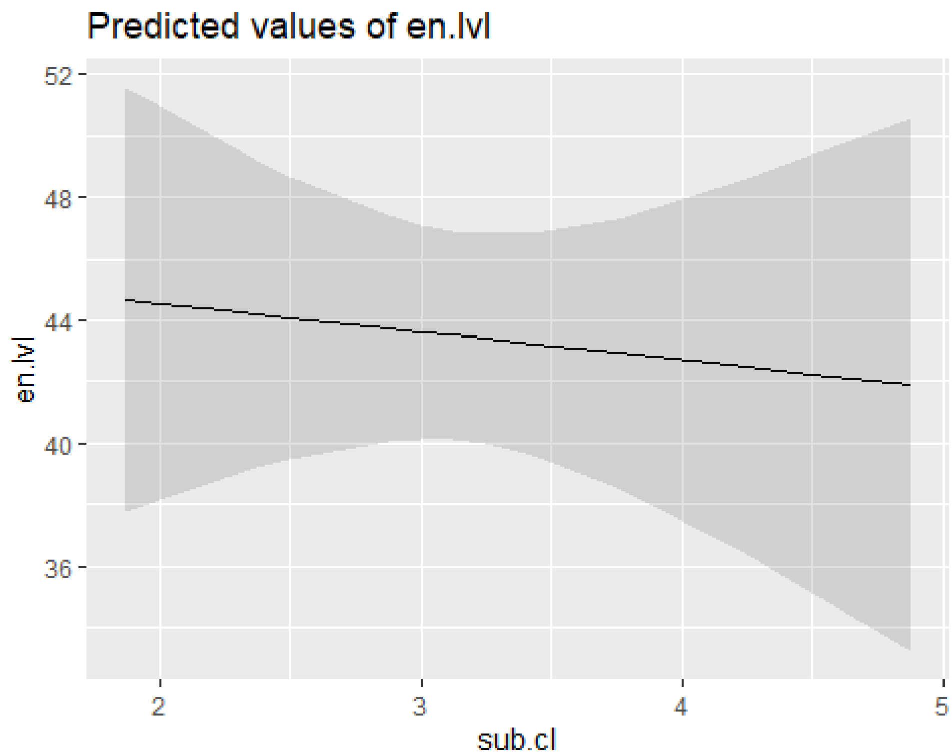
```
plot_model(lm2, "eff")
```

```
## Package `effects` is not available, but needed for `ggeffect()`. Either install package `effects`, or use `ggpredict()`. Calling `ggpredict()` now.FALSE
```

```
## $ob.cl
```

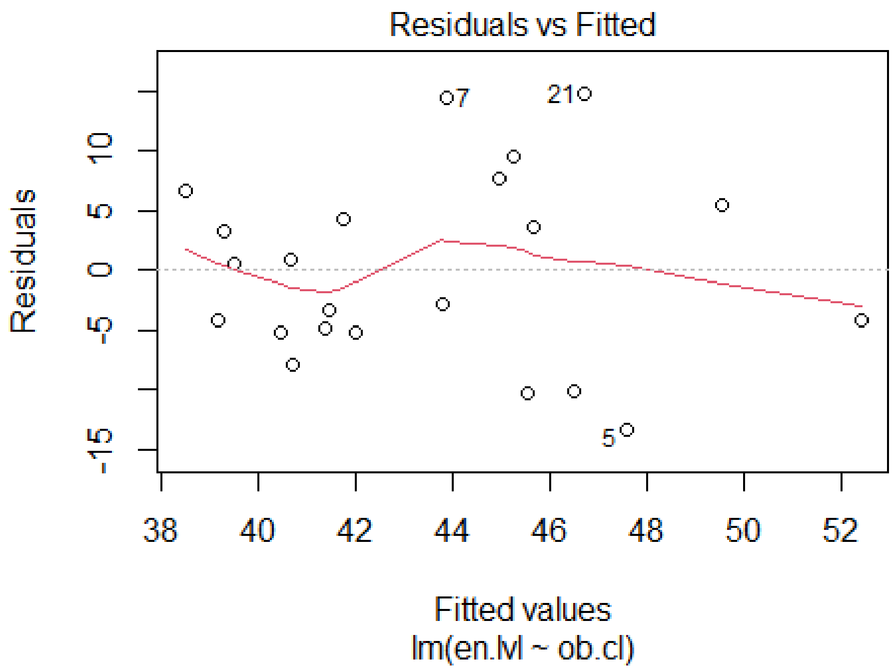


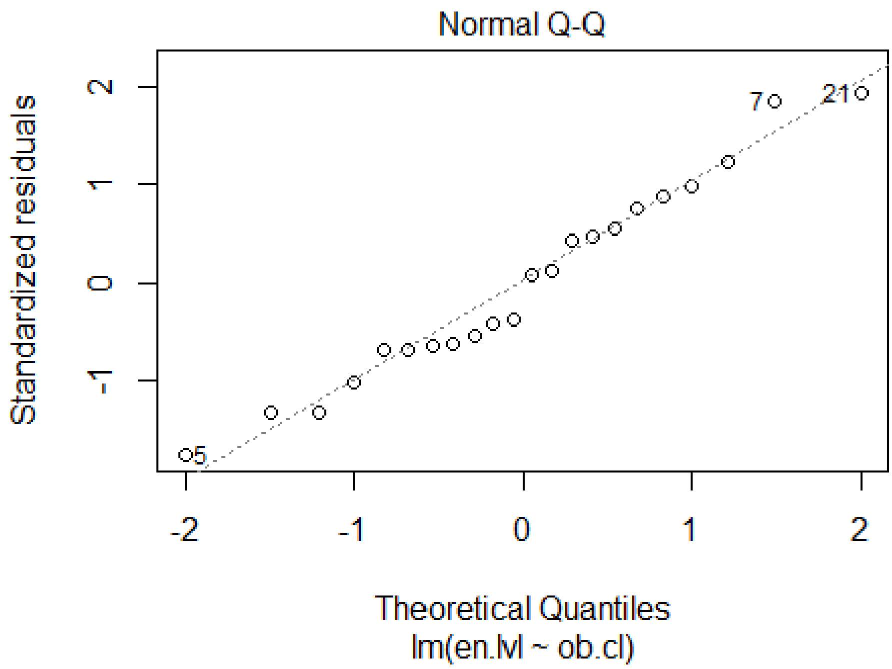

```
##
## $sub.cl
```

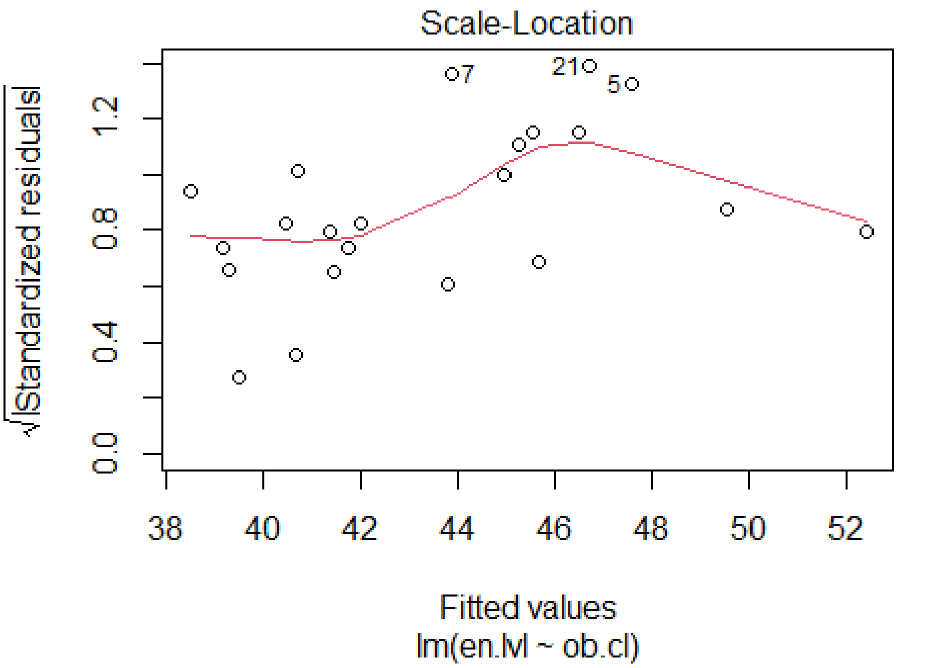


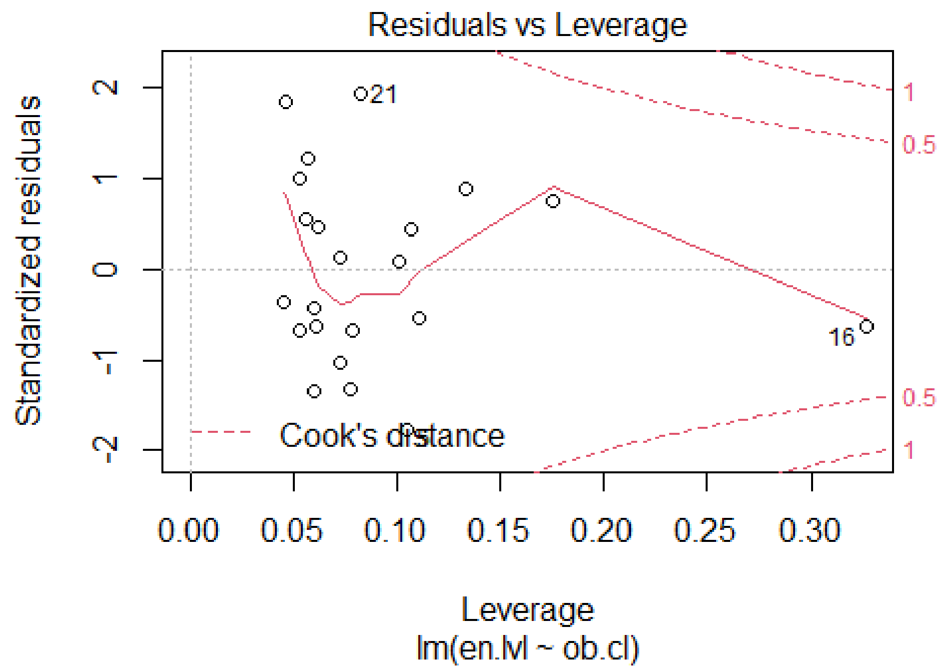
Removing non significant component subjective cogntive load

```
lm2_1 <- lm(en.lvl ~ ob.cl, R_Data )
plot(lm2_1)
```









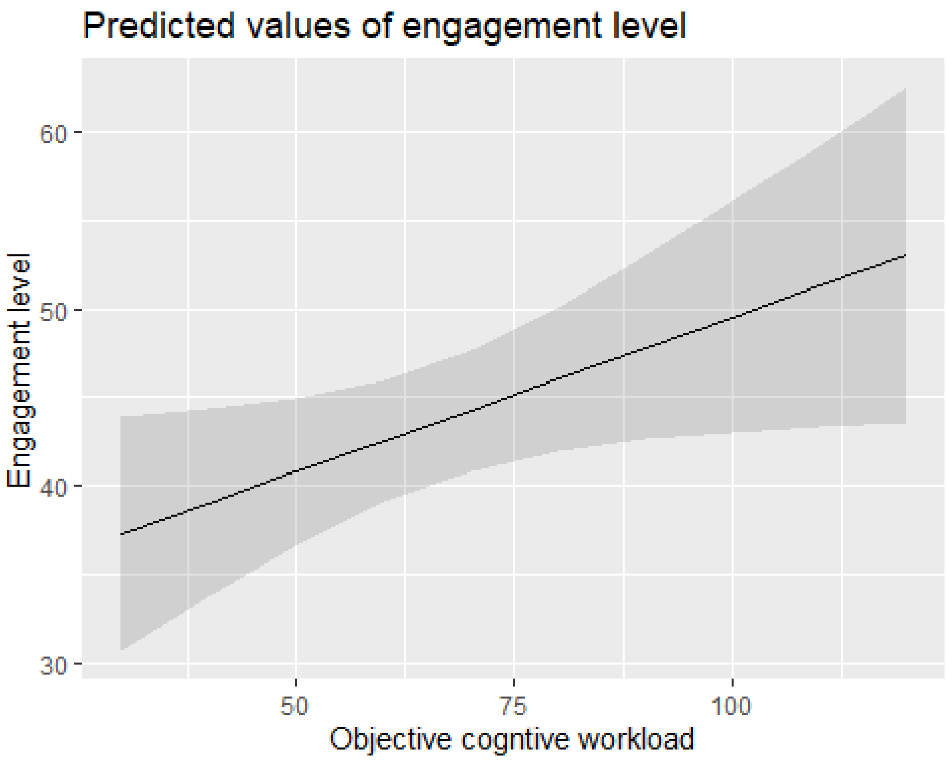

```
summary(lm2_1)

##
## Call:
## lm(formula = en.lvl ~ ob.cl, data = R_Data)
```

```
##
## Residuals:
## Min 1Q Median 3Q Max
## -13.239 -5.107 -1.145 5.189 14.736
##
## Coefficients:
## Estimate Std. Error t value Pr(>|t|)
## (Intercept) 32.0302 5.6633 5.656 1.55e-05 ***
## ob.cl 0.1752 0.0827 2.119 0.0468 *
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 7.956 on 20 degrees of freedom
## Multiple R-squared: 0.1833, Adjusted R-squared: 0.1425
## F-statistic: 4.489 on 1 and 20 DF,  p-value: 0.04683
```

```
plot_model(lm2_1, "eff", title = 'Predicted values of engagement level', axis.title = labs(x = 'Objective cogntive workload', y='Engagement level' ))
```

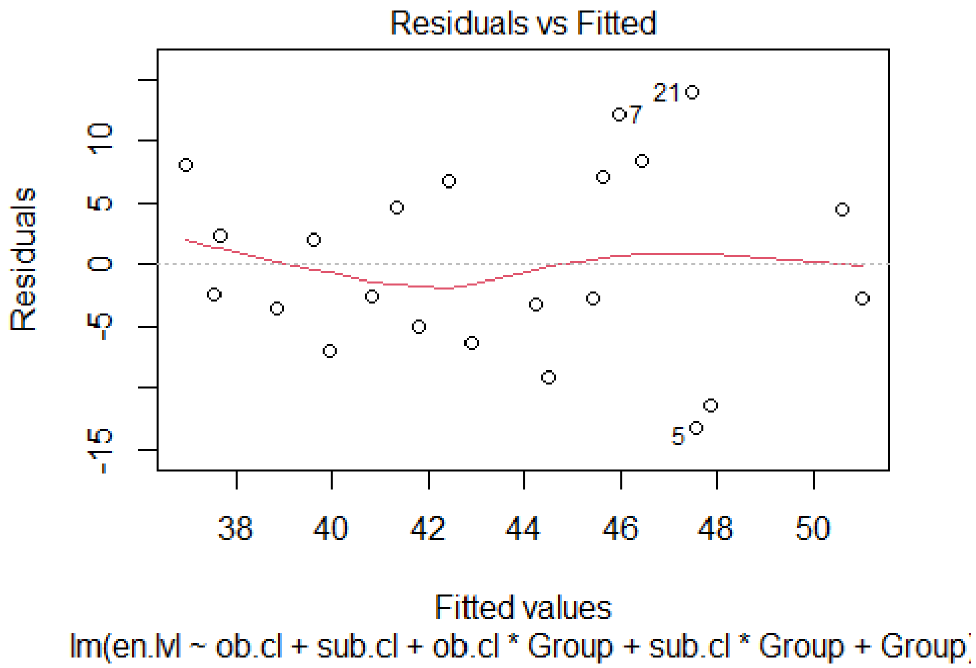
```
## Package `effects` is not available, but needed for `ggeffect()`. Either install package `effects`, or use `ggpredict()`. Calling `ggpredict()` now.FALSE
```

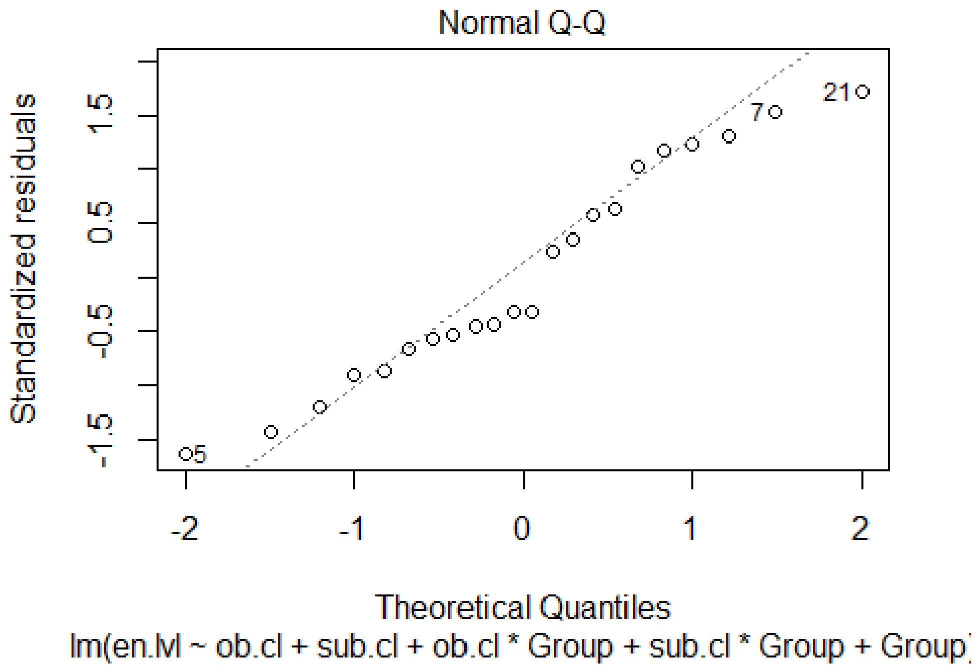
```
## $ob.cl
```

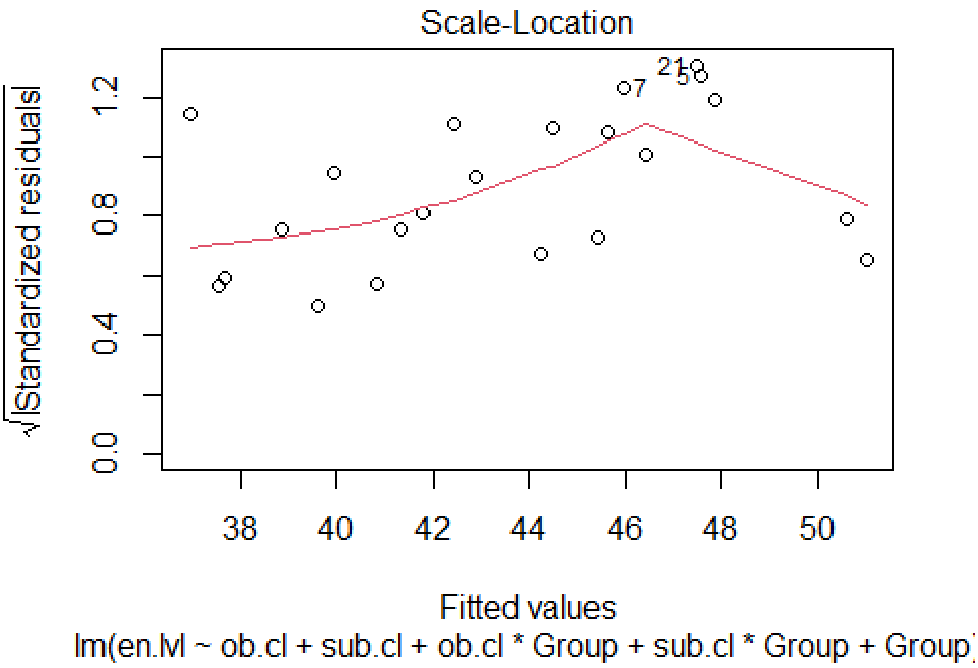


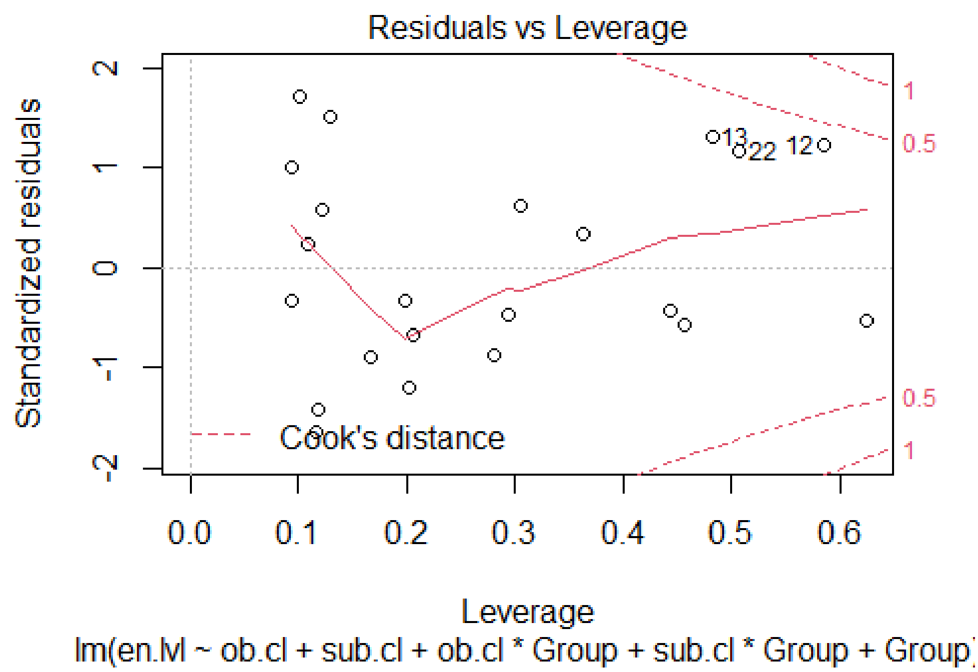
#Lineair regression model within groups

```
lm1 <- lm(en.lvl ~ ob.cl + sub.cl + ob.cl * Group + sub.cl * Group + Group, R_Data )
plot(lm1)
```


Residuals vs Fitted
Residuals
Fitted values
lm(en.lvl ~ ob.cl + sub.cl + ob.cl * Group + sub.cl * Group + Group)


Normal Q-Q
Standardized residuals
Theoretical Quantiles
lm(en.lvl ~ ob.cl + sub.cl + ob.cl * Group + sub.cl * Group + Group)



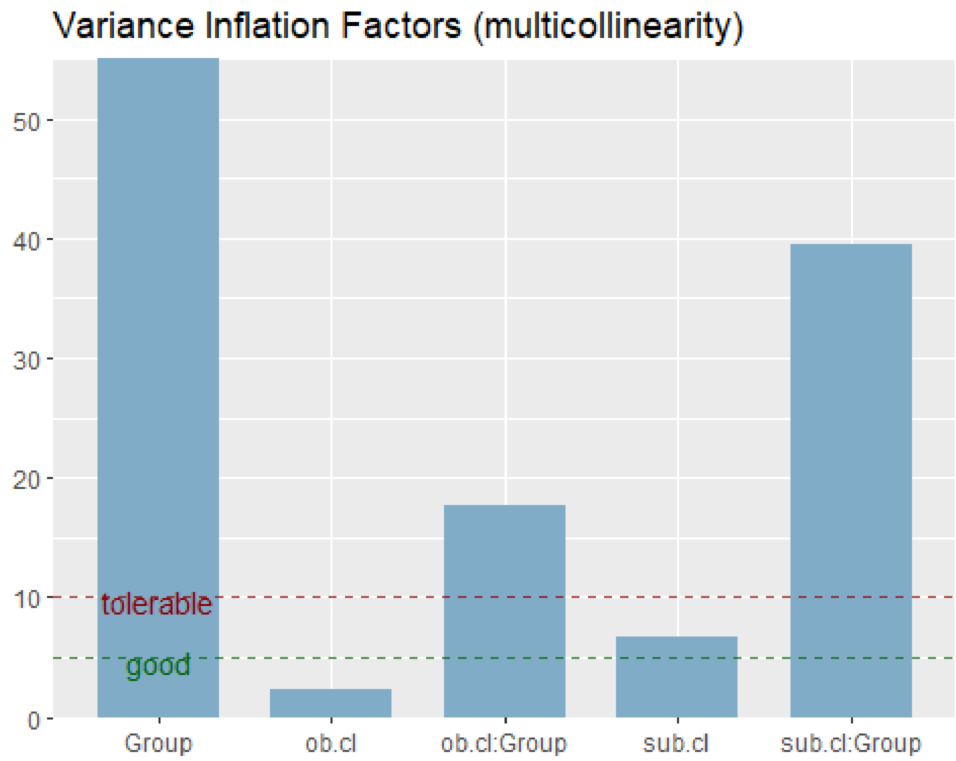



```
summary(lm1)

##
##                                                              Call:
## lm(formula = en.lvl ~ ob.cl + sub.cl + ob.cl * Group + sub.cl *
```

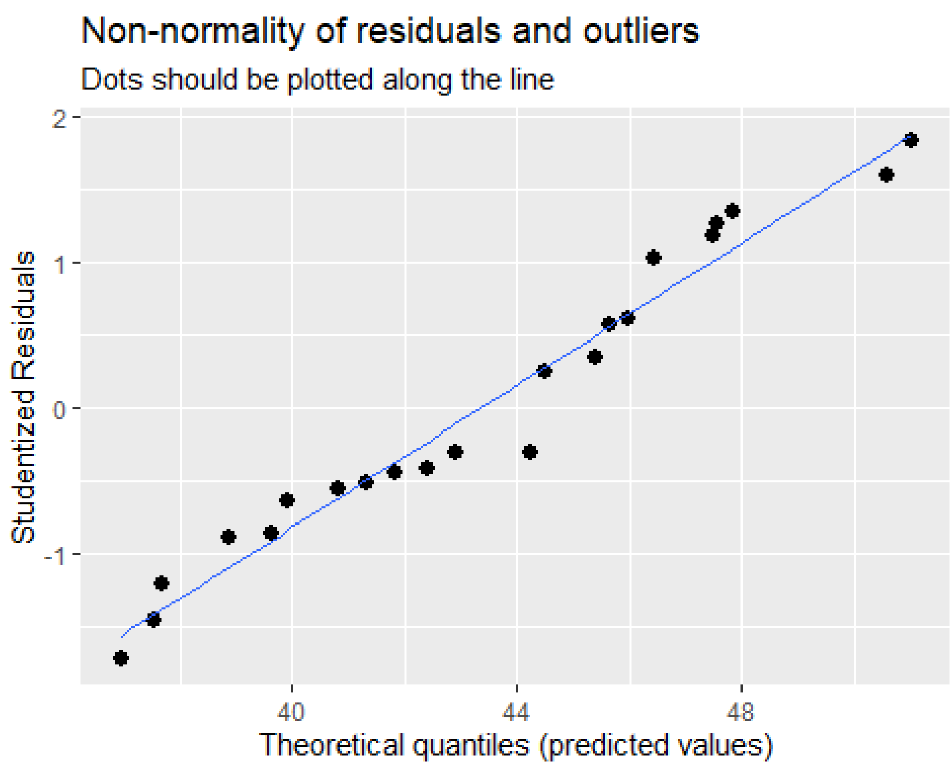
```
## Group + Group, data = R_Data)
##
## Residuals:
## Min 1Q Median 3Q Max
## -13.211 -4.711 -2.567 6.289 13.977
##
## Coefficients:
## Estimate Std. Error t value Pr(>|t|)
## (Intercept) 50.9815 21.4012 2.382 0.030 *
## ob.cl 0.1250 0.1379 0.907 0.378
## sub.cl -4.3016 6.4299 -0.669 0.513
## GroupExperimental -22.5313 27.2547 -0.827 0.421
## ob.cl:GroupExperimental 0.1199 0.2856 0.420 0.680
## sub.cl:GroupExperimental 4.0318 7.0257 0.574 0.574
## ---
## Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 8.622 on 16 degrees of freedom
## Multiple R-squared: 0.2325, Adjusted R-squared: -0.00731
## F-statistic: 0.9695 on 5 and 16 DF,  p-value: 0.4654
```

```
plot_model(lm1, "diag")
```

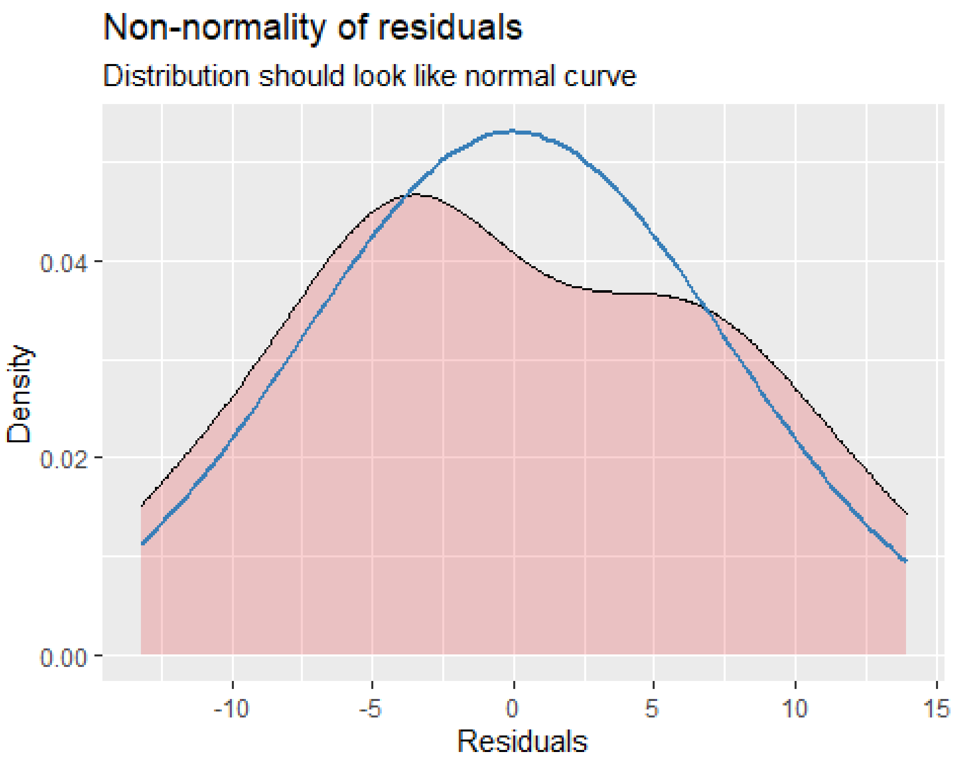
```
## [[1]]
```



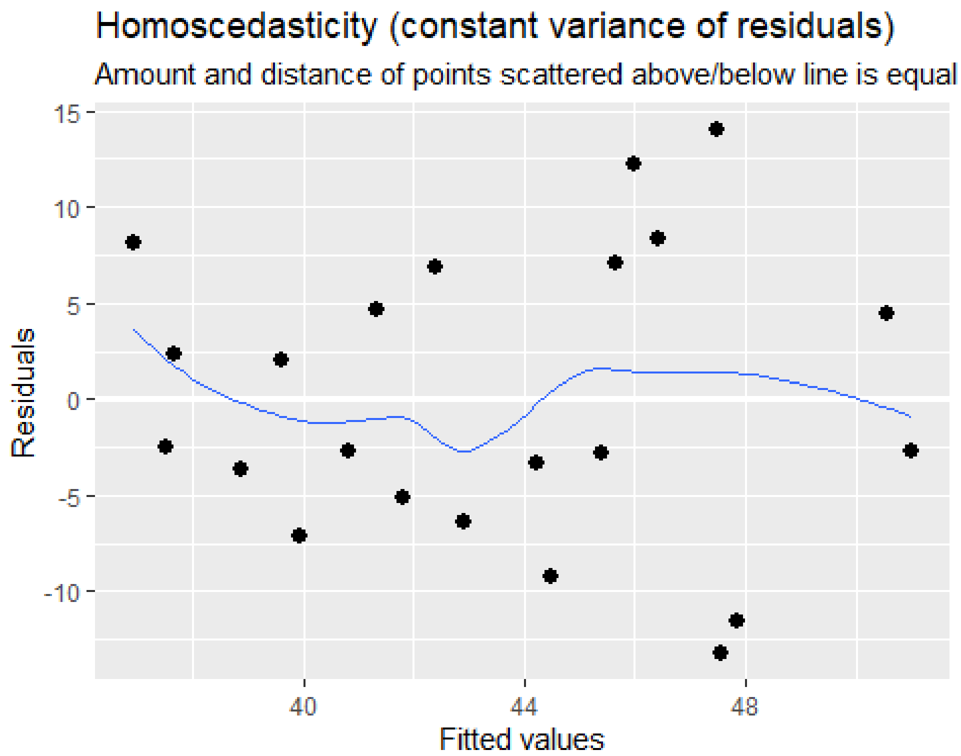

```
##
## [[2]]

## `geom_smooth()` using formula 'y ~ x'
```



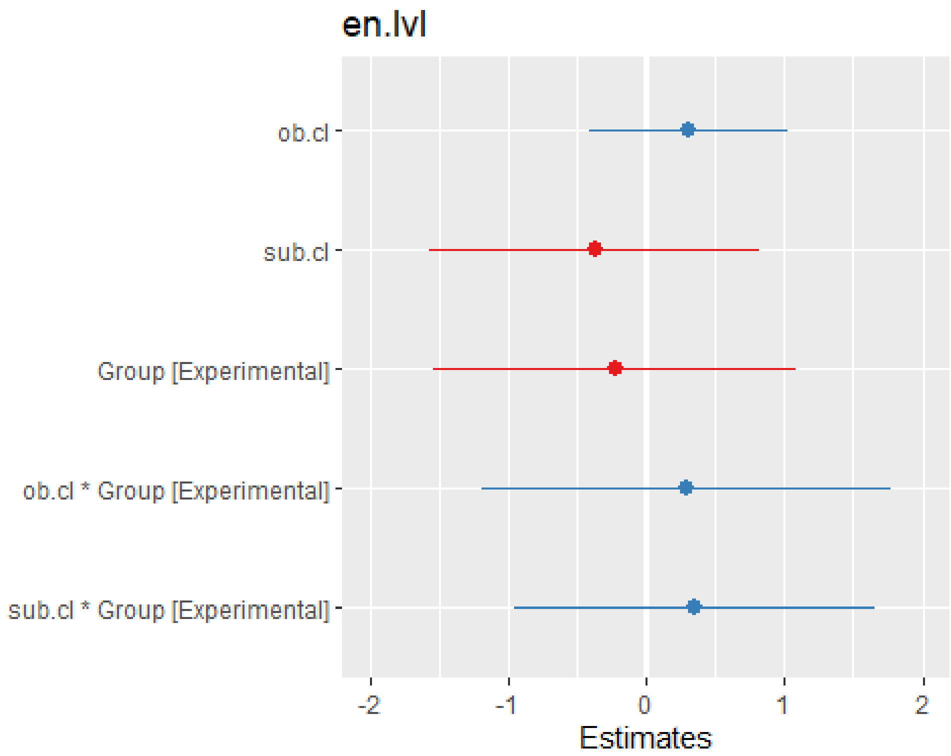
```
##
## [[3]]
```



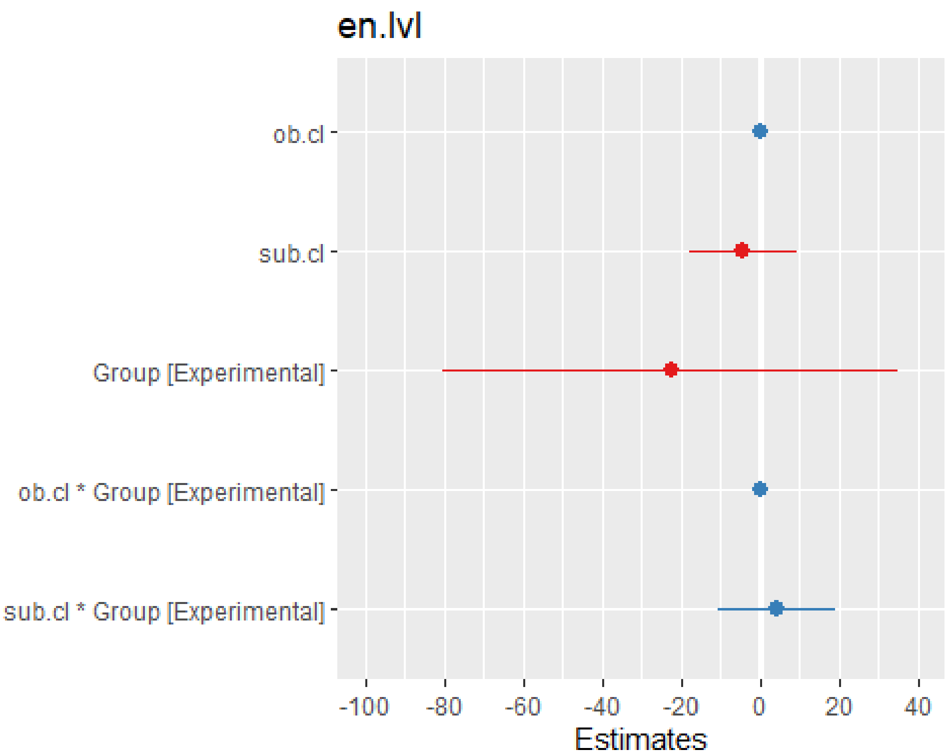

```
##
## [[4]]

## `geom_smooth()` using formula 'y ~ x'
```



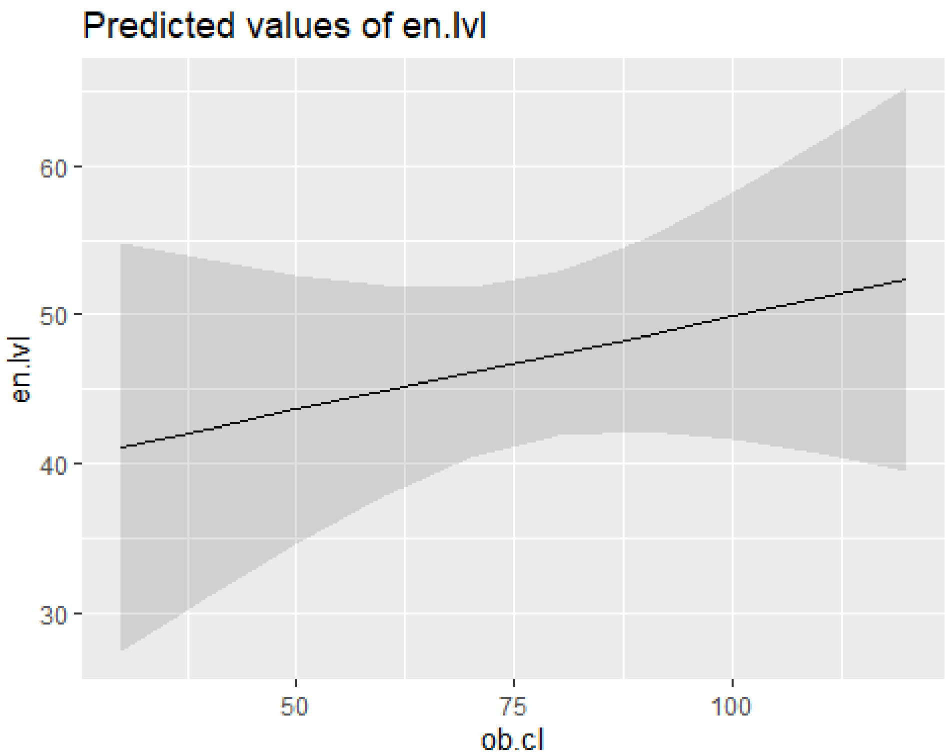

```
plot_model(lm1, "std" )
```



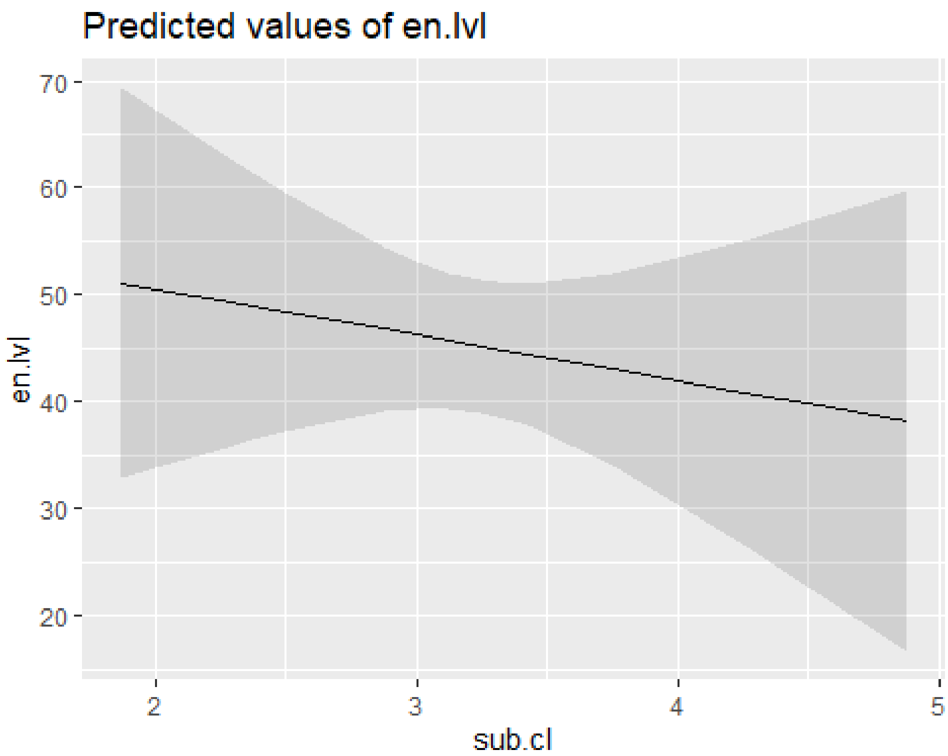

```
plot_model(lm1, "est")
```



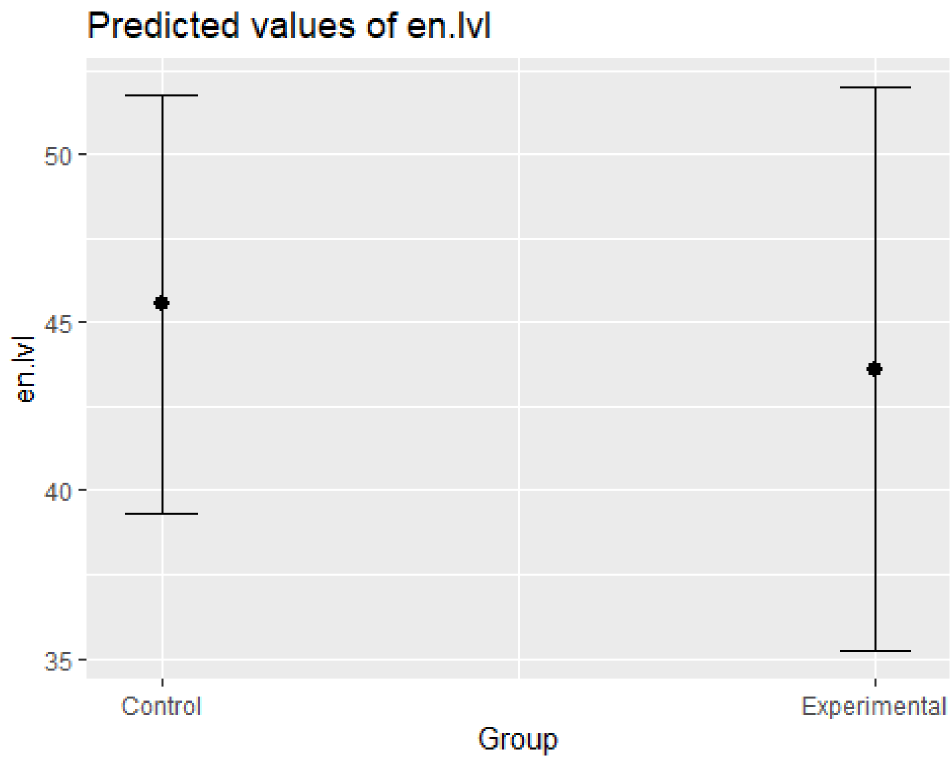

```
plot_model(lm1, "eff")

## Package `effects` is not available, but needed for `ggeffect()`. Either install package `effects`, or use `ggpredict()`. Calling `ggpredict()` now.FALSE

## $ob.cl
```


Predicted values of en.lvl
60
50
40
30
en.lvl
50
75
100
ob.cl

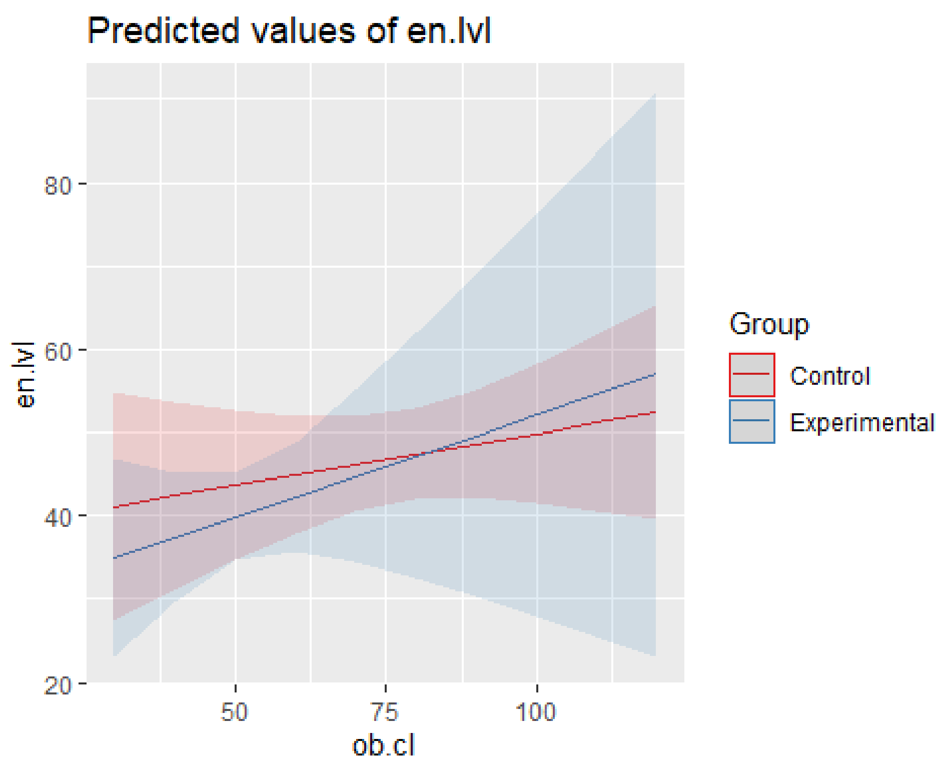
```
##
## $sub.cl
```


Predicted values of en.lvl
70
60
50
40
30
20
en.lvl
2
3
4
5
sub.cl

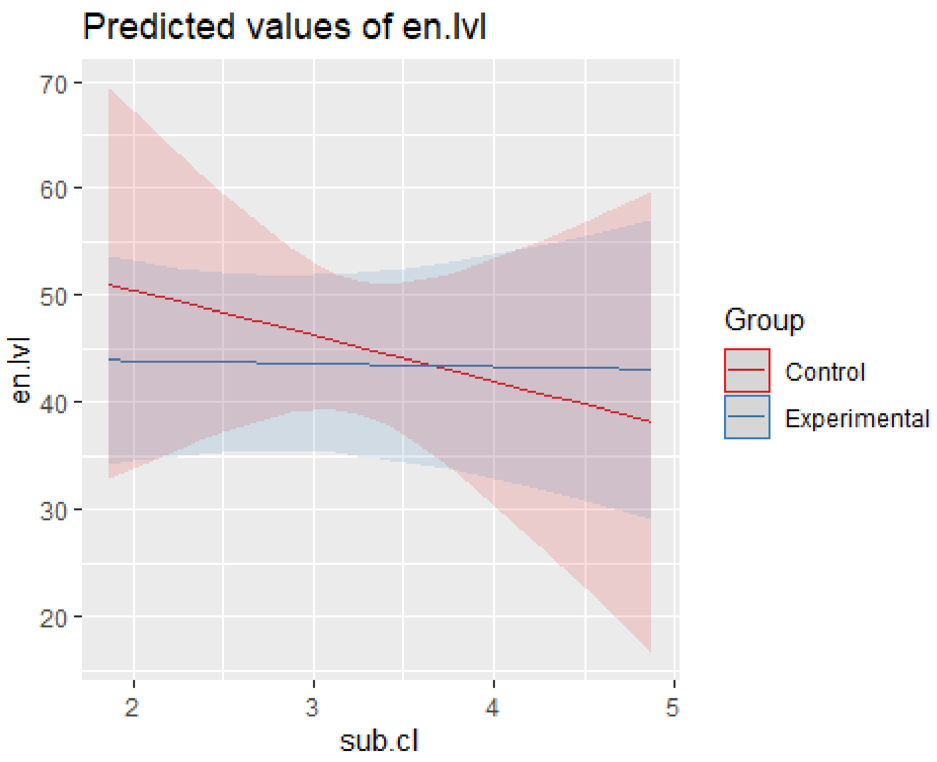
```
##
## $Group
```



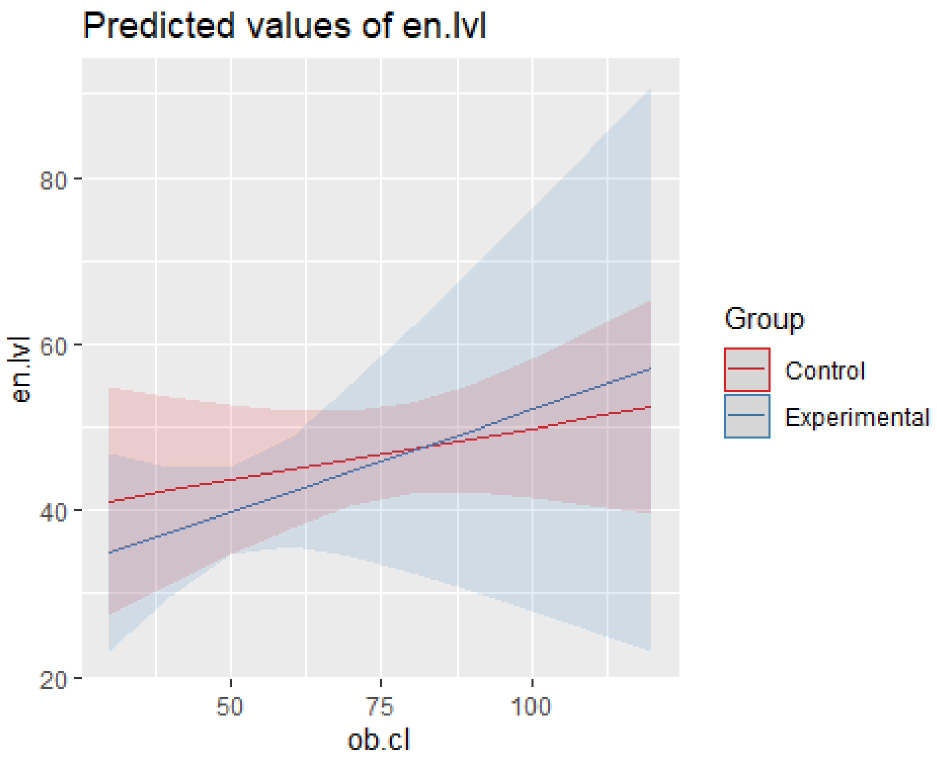

```
plot_model(lm1, "eff", terms = c("ob.cl", "Group"))

## Package `effects` is not available, but needed for `ggeffect()`. Either install package `effects`, or use `ggpredict()`. Calling `ggpredict()` now.FALSE
```



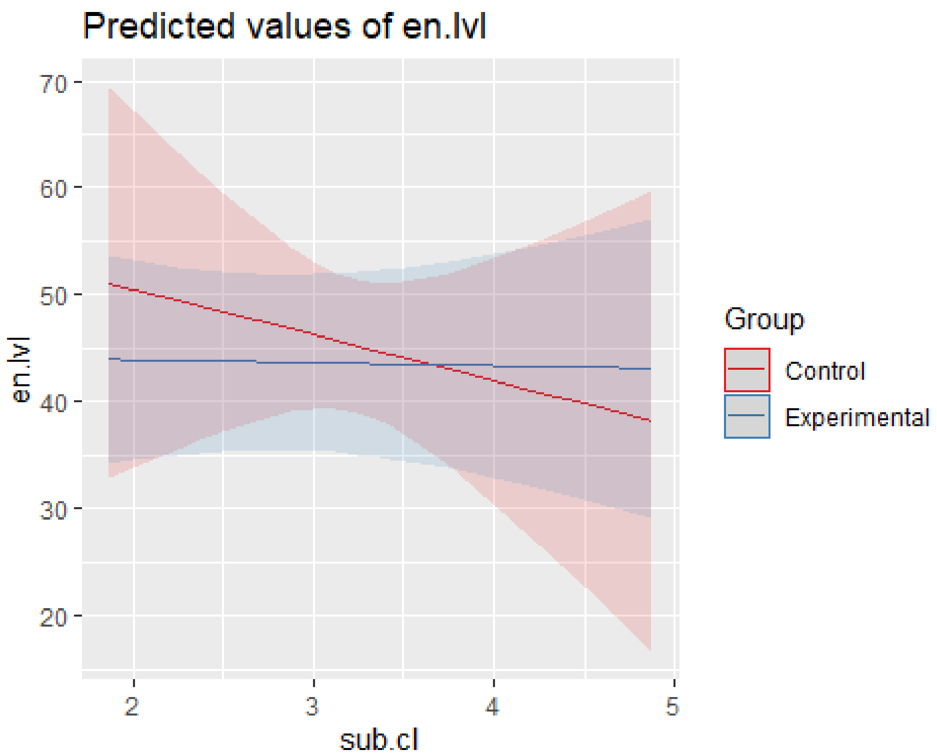
```
plot_model(lm1, "eff", terms = c("sub.cl", "Group"))

## Package `effects` is not available, but needed for `ggeffect()`. Either install package `effects`, or use `ggpredict()`. Calling `ggpredict()` now.FALSE
```




```
plot_model(lm1, "int")

## [[1]]
```

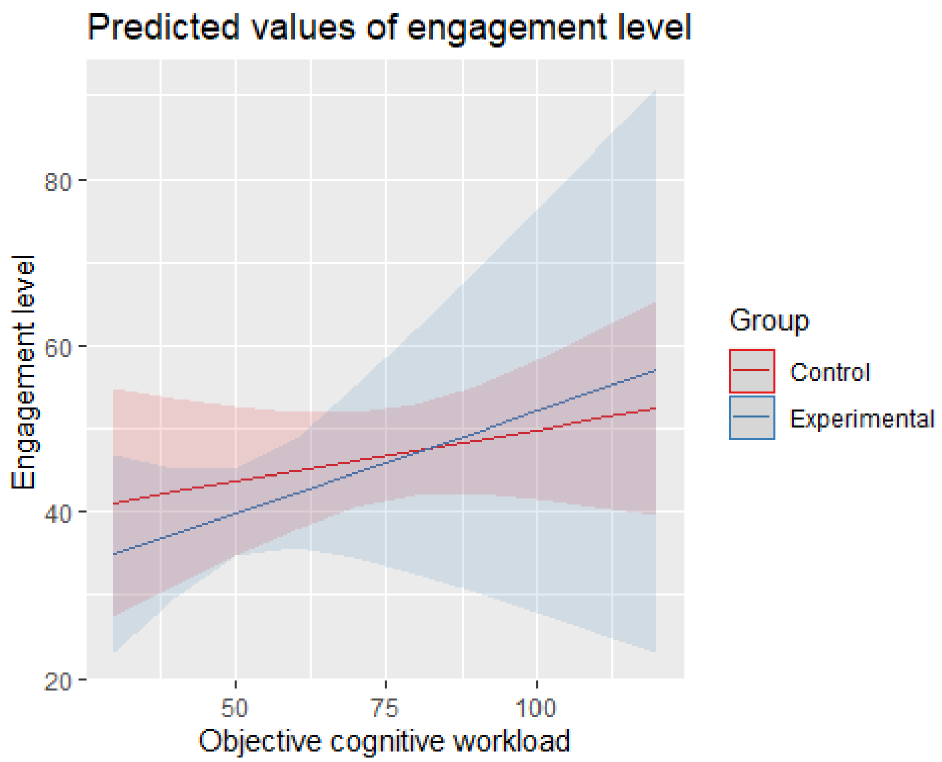



```
##
## [[2]]
```



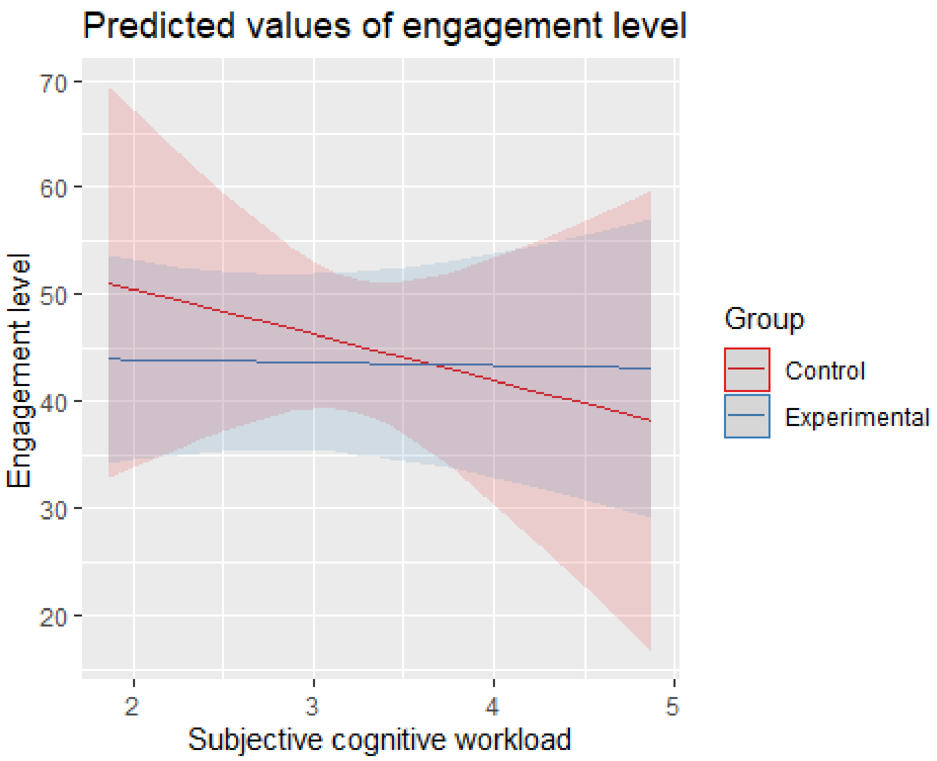

```
plot_model(lm1, "eff", terms = c("ob.cl", "Group"), title = 'Predicted values of engagement level', axis
.title = labs(x = 'Objective cognitive workload', y = 'Engagement level'))
```

```
## Package `effects` is not available, but needed for `ggeffect()`. Either install package `effects`, or use `ggpredict()`. Calling `ggpredict()` now.FALSE
```




```
plot_model(lm1, "eff", terms = c("sub.cl", "Group"), title = 'Predicted values of engagement level', axis.title = labs(x= 'Subjective cognitive workload', y= 'Engagement level'))
```

```
## Package `effects` is not available, but needed for `ggeffect()`. Either install package `effects`, or use `ggpredict()`. Calling `ggpredict()` now.FALSE
```



Predicted values of engagement level
Engagement level
70
60
50
40
30
20
2
3
4
5
Subjective cognitive workload
Group
Control
Experimental