The effect of the task locations on a pointing task performed in a VR spatial navigation study

by

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Declaration of Authorship

I hereby certify that the work presented here is, to the best of my knowledge and belief, original and the result of my own investigations, except as acknowledged, and has not been submitted, either in part or whole, for a degree at this or any other university.

City, Date

Signature

Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbständig und nur unter Benutzung der angegebenen Literatur und Hilfsmittel angefertigt habe. Die Stellen, die anderen Werken – auch elektronischen Medien – im Wortlaut oder dem Sinn nach entnommen sind, sind durch Quellenangaben im Text deutlich gekennzeichnet. Die Arbeit wurde bisher in gleicher oder ähnlicher Form keiner anderen Prüfungsbehörde vorgelegt und auch noch nicht veröffentlicht.

Datum

Unterschrift

Abstract

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1. Introduction

- what is space and how is it related to human cognition
- what is spatial navigation
- role and place of distance in navigation
- VR and spatial navigation
- hypothesis
- why studying this hypothesis
- we are looking at role of distance in the accuracy and RTs in the pointing task

2. Methodology

2.1. Participants

A total number of 26 participants, # females and rest with the average age of average age with the standard deviation of sd age took part in the experiment. The participants were all students of the University of Osnabrück. Before the start of the first exploration session all participant gave their written consent for taking part in the experiment (see appx. E, Einverständniserklärung). The participation was voluntary and only students with no health issue were selected (see appx. E, Anamnese). The participants were compensated by test-subject hours and/or 5€ per hour.

Due to the Covid-19 pandemic sessions were conducted according to the laboratory hygiene regulations with a mask and under 3G rule.

3 participants were excluded due to not being able to comply with the experimental requirements, i.e., come in less than 3 days and more than 4 hours apart.

2.2. Experimental Design

2.2.1. City

This study is conducted in a virtual reality (VR) city with an area of about 1 km². The city is consisted of 284 buildings. 56 buildings are used in the experimental task of this study from which 4 are global landmarks, 26 are `context meaningful` locations, e.g., shops, construction sites, and 26 are residential, `not context meaningful` buildings. These 56 buildings have human agents in front of them and an artwork on one of their walls. Human agents belonging to the shops take the pose of an act according to the functionality of that store `(meaningful)`, e.g., has a book in the hand in front of a bookstore, or are just standing in front of the residential building `(standing human agent)`. The artworks on the shops are also depicting the functionality of the shop.

A sun with a detectable origin is avoided in the city, no street is named and no building is numbered to implicitly direct the participants to prioritize their spatial learning.

- FIG: include a map
- include photos of the city

2.2.2. Application and Technology

The application of the experiment is implemented with unity version 2019.4.11f1. The assets of the city, e.g., buildings, streets were obtained from a previous study called SpaRe, made also at the university of Osnabrück. They were modified with blender version 2.83 LTS (Long Term Support), as were also the human agents picked from Adobe Mixamo collection. They were modified for this experiment in a way that some contextual objects were added to the human agents in front of context meaningful buildings with regard to the context of the building.
The experiment consisted of two separate parts, i.e., Exploration and Testing. Each section had the option to choose the language of the instructions, i.e., German and English. The experiment was conducted using a HTC Vive Pro Eye VR-Headset. For the virtual moving purposes inside the virtual city the participants were given Index valve controller to navigate inside a city by moving the joystick of the controller. They had both the right and left controllers to be able to use their dominant hand.

2.3. Experimental Procedure

Participants were seated on a backless rotating chair that enabled them to physically rotate in the virtual city. Any forward, backward and sideways movement were done utilizing the controllers.

2.3.1. Exploration

The exploration consisted of 5 sessions. The sessions had to be no more than 3 days and no less than 4 hours apart.
The total duration of each session was 30 minutes broke down into 10 minutes segments for breaks to reduce the possibility of motion sickness. Before starting each segment the built-in eye-tracker of the VR-Headset was calibrated and validated.

After inserting participant-ID and choosing the preferred language the exploration session started with a tutorial. The tutorial was held in a scene separate from the main city. The purpose of the tutorial was to allow the participant to move around, get acquainted with the controller and practice the possible movement options the experiment allowed for. After participants confirmed their confidence in using the controllers the experiment was continued to the exploration session. In the main city participants were advised to explore the city freely.

2.3.2. Testing

Testing comprised of one session of approximately 2 hours. The testing starts after inputting the participant-ID and choosing the language. There is then a tutorial scene outside of the main city used in the experiment for participants to get acquainted with how to use the controller for performing the tasks. Before presenting the trials and in intervals of 112 trials eye-tracker was calibrated and validated.

Testing was a pointing task comprised 336 trials performed from 28 different starting locations in the city. The distribution of the starting locations can be seen in figure 2.1. At each starting location 12 target buildings were randomly chosen from a pull of 112 targets (56 task buildings with and without human agents). Some examples are shown in figure 2.2. Each of the four conditions of the experiment, i.e., context meaningful with human agent present `(CmA)`, context meaningful with no human agent present `(CmANo)`, non-context meaningful with human agent present `(Sa)`, non-context meaningful with no human agent present `(SaNo)` built up 25% of the trials. The starting locations themselves were consistent for all participants and their order of execution was randomized for each participant. All movements except the rotation were blocked for the whole testing session to maintain the consistence of the participants' position in the starting locations between participants.

At each starting location the 12 consecutive trials were performed. In each trial a photo of one of the task buildings (with or without human agent in front of it) was presented at the top center of the screen (see figure X). The participants had the option to press a button to bring the picture to the middle of the screen (see figure X) and as soon as the button was released the photo moved back to the upper center part of the screen. Since there was no visual virtual body, there was a green dashed laser beam (see figure X) attached to the virtual hand of the participants that moved as they moved

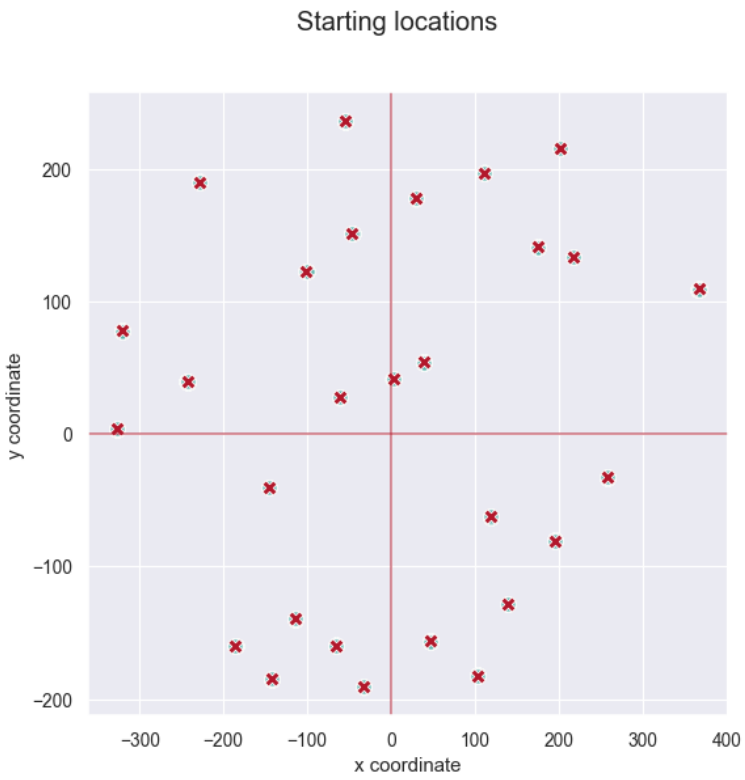

Figure 2.1.: distribution of the starting locations in the city

their hand. The purpose of the laser beam was to assist the participants with the visualization of the direction they are pointing at. The maximum duration of each trial was 30 seconds. If there was no answer given to the task after 20 seconds from the start of the trial, i.e., no direction was selected by the participant indicating in which direction the target building is located from their current location, a countdown timer appeared on the bottom center of the screen (see figure X) and terminated the trial after 10 seconds if there was still no answer given.

Selecting an answer for the task, i.e., selecting the direction of the target building was possible with a button press. With once pressing the button it locked the laser beam onto a direction and detached it from the hand maybe a figure of the controller with the info?. The participants had the option to either confirm the chosen direction with the same button or cancel it with another. Moving on to the next trial was the result of either the participant confirming a direction or by running out of time. Behavioral and technical data, e.g., the chosen direction, participant position and rotation, reaction times were gathered during each trial. The human agents were present during the testing in the city at their exact designated positions and poses

a) CmA b) CmANo

c) Sa d) SaNo

Figure 2.2.: Examples of photos shown in the pointing task as target buildings. A selection of all four experimental conditions. **CmA:** context meaningful with human agent present. **CmANo:** context meaningful without human agent present. **Sa:** not context meaningful with human agent present. **SaNo:** not context meaningful without human agent present.

in the exploration sessions. A gray screen fade out and fade in occurred while transporting the participants from their current location to another starting location. This was to serve the purpose of decreasing the chance of motion sickness and also avoiding leaking environmental information while moving in the city.

- include photo of the trial

2.4. Analysis method

The data of this experiment is gathered from unity in JSON [1] format. All the further processes for analysis were done in python (Van Rossum & Drake,

[1] Introducing JSON: https://www.json.org/json-en.html

2009) v3.8. For the preprocessing the pandas (McKinney, 2010; pandas development team, 2022) and numpy (Harris et al., 2020) libraries, and for the analysis python's statmodels (Seabold & Perktold, 2010) module were utilized. Matplotlib (Hunter, 2007) and Seaborn (Waskom, 2021) were used for the visualizations.

After importing and converting the data into a pandas dataframe, the preprocessing is done to prepare the data for analysis. In this process the dependent variable `absolute_180_angle` is derived. The variable contains the absolute angular error between the participant's chosen direction and the actual target position.

2.4.1. Preprocessing

Different functions of pandas `(pd)` and numpy `(np)` used for the preprocessing. In all the calculations involving directions and positions, only the right direction (x) and the forward direction (z) are taken into account. The up direction (y) was excluded as it is not relevant for the analysis at hand.

The main preprocessing steps are as follow:

1. Removed trials in which the participants did not select any direction. These were the trials that were terminated due to timeout. Hence, only the trials where their respective TimeOut variable was False were kept for the analysis.
2. Calculated the absolute angular error between participant's chosen direction and the actual location of the target building.

    a) Translated the target building's center position `(Tpos)` by the participant's body position `(Ppos)` to be able to derive the translated building center position $Tpos\_t$ take the body position as the origin at the (0,0) coordinates.

$$Tpos\_t_{x,z} = Tpos_{x,z} - Ppos_{x,z}$$

    The direction vector of participant's chosen direction doesn't need to be translated because unity's output for a direction is a normalized vector and therefore it's origin lies already at (0,0).

b) Now that body position is at (0,0) with respect to the translated building center position, the angle difference between the participant's chosen direction `(Cdir)` to the positive x-axis and the translated building center position `(Tpos_t)` to the positive x-axis were calculated using numpy arctan2(z, x) [2] function. This function calculates the angle in radian between the positive x-axis and the vector given to the function as parameter.
Due to the translation done in step *a* the body position was implicitly translated to the origin (0,0), i.e., subtracting body position from body position results in (0,0), it was possible to pass the z and x coordinates of the `Tpos_t` and the `Cdir` to the arctan2 function separately to calculate the angle between the `Cdir` and the positive x-axis `(Cdir_to_x)` and the `Tpos_t` and the positive x-axis `(Tpos_to_x)`. The results are directly translated to degree utilizing numpy rad2deg() [3] function.

$$Tpos\_to\_x_\theta = np.rad2deg(np.arctan2(Tpos\_t_z, Tpos\_t_x))$$
$$Cdir\_to\_x_\theta = np.rad2deg(np.arctan2(Cdir_z, Cdir_x))$$

c) After creating `Tpos_to_x` and `Cdir_to_x` the angles were respectively converted to `Tpos_to_x_360` and `Cdir_to_x_360` in the 360 degree environment.

$$Tpos\_to\_x\_360_\theta = \begin{cases} 360 + Tpos\_to\_x_\theta & \text{if } Tpos\_to\_x_\theta < 180 \text{ then} \\ Tpos\_to\_x_\theta & \text{else} \end{cases}$$

[2] Numpy arctan2: https://numpy.org/doc/stable/reference/generated/numpy.arctan2.html
[3] Numpy rad2deg: https://numpy.org/doc/stable/reference/generated/numpy.rad2deg.html

$$Cdir\_to\_x\_360_\theta = \begin{array}{l} if \\ \qquad Cdir\_to\_x_\theta < 180 \\ then \\ \qquad 360 + Cdir\_to\_x_\theta \\ else \\ \qquad Cdir\_to\_x_\theta \end{array}$$

d) Calculated the angular difference between the selected direction (`Cdir_to_x_360`) and the target building (`Tpos_to_x_360`). They were directly converted to the signed 2 quadrant environment.

$$signed\_180\_angles_\theta = ((Tpos\_to\_x\_360_\theta - Cdir\_to\_x\_360_\theta) + 180)\%360 - 180$$

e) The final step was to create `absolute_180_angles` (see figure 2.3), the dependant variable for the main analysis in LMM. This variable stores the absolute value of the angular differences contained in `signed_180_angles`. The reason for using absolute values is that the direction of the deviation is not a deciding factor in how accurate the participants performed the pointing task. Taking the absolute values is done with numpy abs() [4] function.

$$absolute\_180\_angles_\theta = np.abs(signed\_180\_angles_\theta)$$

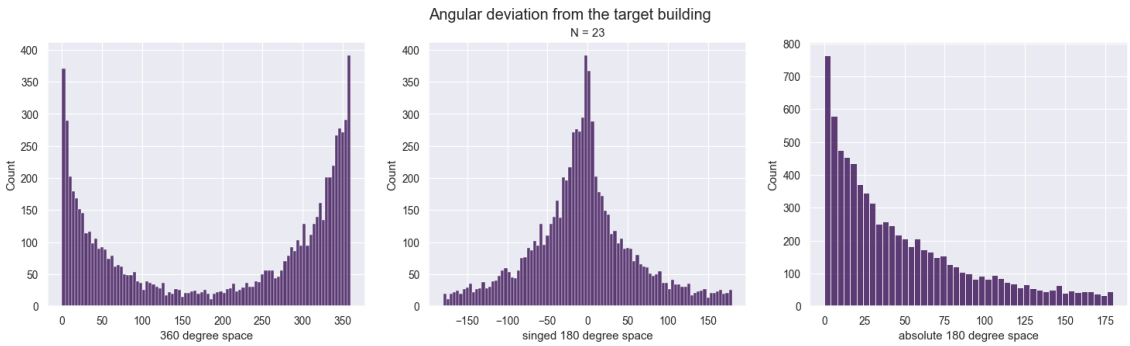

Figure 2.3.: distribution of the angular error

[4] Numpy absolute: https://numpy.org/doc/stable/reference/generated/numpy.absolute.html

2.4.2. Analysis

Due to the hierarchical structure of the data, Linear Mixed Models (LMM) were chosen as the method of analysis. For that the python's statmodels module were used.

- linear mixed models parameters

3. Results

- reporting the results of the analysis
- add figures

4. Conclusion

- in case there are differences found between starting locations discuss the reasons
- if there are previous studies, compare the results
- discuss limitations and suggest improvements if needed
- what can be done further on this topic
- summarize conclusion

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Appendix

Appendix A.

Collected Variables

list of variables gathered + explanation

Appendix B.

Plots

plots that are not used but could be informative

Appendix C.

Task buildings

list of task buildings with their specification

Appendix D.

Experimental protocol

the complete experimental protocol

Appendix E.

Forms

Einverständniserklärung

Titel der Studie: Untersuchung des Effektes von menschlichen Avataren auf räumliches Lernen und räumliche Navigation in einer virtuellen Stadt unter Einbeziehung des Blickverhaltens

Zweck der Studie: Das Ziel des vorliegenden Forschungsprojekts ist es, den Effekt von menschlichen Avataren auf das Lernen durch aktive Navigation in einer virtuellen Stadt zu untersuchen. Zu diesem Zweck werden wir menschliche Avatare strategisch neben Gebäuden innerhalb einer virtuellen Stadt platzieren. Auf Basis der erhobenen Daten werden wir evaluieren, ob die Teilnehmer sich die Teile der Stadt, in denen wir Avatare platziert haben, besser merken konnten.

Projektleitung: Prof. Dr. Peter König, Dr. med. Sabine König, Prof. Dr. Gordon Pipa, Tracy Sánchez (Lic.), Institut für Kognitionswissenschaften, Wachsbleiche 27, 49082 Osnabrück

Sehr geehrte Studienteilnehmerin, sehr geehrter Studienteilnehmer, hiermit bitten wir Sie um Ihre Einwilligung zur Teilnahme an dem oben genannten Forschungsvorhaben und zur Nutzung Ihrer personenbezogenen Daten, wie sie Ihnen in der Probandeninformation und der Aufklärung näher erläutert worden sind.

I. Allgemeines

Hiermit erkläre ich, _____, geboren am _____, dass ich durch die Projektleitung mündlich und schriftlich über das Wesen, die Bedeutung, die Risiken und Folgen der wissenschaftlichen Untersuchungen im Rahmen der o.g. Studie informiert und aufgeklärt wurde und ausreichend Gelegenheit hatte, meine Fragen mit der Projektleitung zu klären.

Mir ist bekannt, dass ich das Recht habe, meine Einwilligung jederzeit ohne Angabe von Gründen und ohne nachteilige Folgen für mich zurückzuziehen. Mir ist bekannt, dass meine Daten nach Abschluss der Datenerhebung nur in anonymisierter Form gespeichert, analysiert und veröffentlicht werden. Dies führt dazu, dass ein späteres Löschen meiner Daten nicht mehr möglich ist, da die Daten nicht mehr meiner Person zugeordnet werden können.

Ich habe eine Kopie der schriftlichen Studieninformation und der Einwilligungserklärung erhalten.

Ich erkläre, dass ich freiwillig bereit bin, an der wissenschaftlichen Studie, die für mich aus 5 wiederholten Erkundungen in der virtuellen Stadt „Westbrück“, die jeweils 45 Minuten dauern werden und einer Testsession in der virtuellen Umgebung, die ungefähr 120 Minuten dauern wird, teilzunehmen. Die Erkundungs- und Testsessions finden jeweils an unterschiedlichen Tagen statt.

Insbesondere erkläre ich mich damit einverstanden,

1. dass die in der Studie aufgenommenen Daten in anonymisierter Form gespeichert und analysiert werden, auch auf elektronischen Datenträgern;
_____ (Initialen Proband)

2. dass meine persönlichen Daten zu Zwecken der Vergütung und Dokumentation gespeichert werden. Diese persönlichen Daten werden nur in Papierform und nicht mit den experimentellen Daten verbunden aufgehoben.
_____ (Initialen Proband)

3. dass an dieser Studie folgende beteiligte Wissenschaftler Zugang zu den erhobenen anonymisierten experimentellen Daten zum Zweck der Durchführung und wissenschaftlichen Verwertung der Studie haben: Prof. Dr. Peter König, Dr. med. Sabine König, Prof. Dr. Gordon Pipa, Tracy

Sánchez, Institut für Kognitionswissenschaften, Universität Osnabrück;
_____ (Initialen Proband)

4. dass die Studienergebnisse und die Studiendaten in anonymisierter Form, die nach heutigem Stand der Technik keinen Rückschluss auf meine Person zulässt, veröffentlicht werden; die Veröffentlichung kann zum Beispiel in einer wissenschaftlichen Zeitschrift oder im Internet erfolgen;
_____ (Initialen Proband)

5. dass meine Daten, im Sinne der guten wissenschaftlichen Praxis, in anonymisierter Form der Öffentlichkeit über eine Creative Commons Lizenz (CCo) zugänglich gemacht werden;
_____ (Initialen Proband)

6. dass ich aktiv eine virtuelle Stadt erkunde. Anschließend werde ich Orientierungstests in der virtuellen Stadt durchführen. Während des Navigationstrainings werde ich eine virtuelle Realitätsbrille tragen. Die Messungen finden in einem Labor des Instituts für Neurobiopsychologie der Universität Osnabrück statt
_____ (Initialen Proband)

7. dass die in der Studie aufgenommenen Daten entsprechend der Empfehlung durch die DFG mindestens 10 Jahre lang aufbewahrt werden.
_____ (Initialen Proband)

II. Ausschlusskriterien, Verhaltensregeln

II.1 Ausschlusskriterien

Ich versichere, den mir vorgelegten Anamnesebogen wahrheitsgemäß ausgefüllt zu haben. Mir ist bewusst, dass während des Trainings in der virtuellen Stadt „Seekrankheits-“ ähnliche Symptome („Bewegungsübelkeit“) wie Schwindel und Übelkeit auftreten können. Des Weiteren ist mir bewusst, dass das Tragen der virtuellen Brille ein Druckgefühl bis hin zu leichten Kopfschmerzen und ein Verspannungsgefühl im Nacken auslösen kann.

II.2 Zustimmung zur Einhaltung von Verhaltensregeln

Ich wurde vor der Durchführung der Studie darauf hingewiesen, dass ich vor oder während der Untersuchung auftretendes körperliches oder psychisches Unwohlsein der Projektleitung unverzüglich mitzuteilen habe. Ich wurde zusätzlich informiert, dass ich jederzeit während des Experimentes eine Pause einlegen darf.

III. Datenschutzrechtliche Einwilligungserklärung

Einblick in die anonymisierten Daten durch Dritte findet statt:

Ich bin damit einverstanden, dass die erhobenen Daten in anonymisierter Form in wissenschaftlichen Zeitschriften und über eine Creative Commons Lizens (CC0) im Internet veröffentlicht werden. Dies bedeutet, dass die Daten frei zugänglich sind und frei analysiert und veröffentlicht werden dürfen.

IV. Aufwandsentschädigung

Ich bin damit einverstanden, dass ich für die Teilnahme an der Studie mit 5€ pro Stunde für die Zeit der Exploration und Messungen in VR vergütet werde. Alternativ, wird mir auf Wunsch ein Teil der Zeit entsprechend in Versuchspersonenstunden bestätigt. Weitere Vorteile wurden nicht zugesagt.

V. Unterschrift

Ich erkläre hiermit, dass ich freiwillig und unter Kenntnis der oben genannten Punkte an der Studie „Untersuchung des Effektes von taktiler Wahrnehmungserweiterung auf räumliches Lernen und räumliche Navigation in einer virtuellen Stadt unter Einbeziehung des Blickverhaltens“ teilnehme.

Osnabrück, den _____ _____ (Unterschrift Proband)

Osnabrück, den _____ _____ (Unterschrift Projektleitung)

ALLGEMEINE ANAMNESE (A1)

Bei Problemen mit dem Ausfüllen wenden Sie sich bitte an die studienbegleitenden Mitarbeiterinnen und Mitarbeiter!

VP-Nummer			
Geschlecht:	□ m □ w □ andere	**Datum**:	

Nervensystem

Bewusstseinsstörungen		□ ja	□ nein
Krampfanfälle (Epilepsie)		□ ja	□ nein
Schwindel/Gleichgewichtsstörung		□ ja	□ nein
Seekrankheit/"Bewegungsübelkeit"	z.B. beim Autofahren	□ ja	□ nein
Tinnitus		□ ja	□ nein
Kopfschmerz	□ gelegentlich	□ oft	□ nein
Migräne	□ gelegentlich	□ oft	□ nein
Tremor (Zittern)		□ ja	□ nein
Gedächtnisprobleme		□ ja	□ nein
Sprach- oder Sprechbeschwerden		□ ja	□ nein
Verhaltensstörungen		□ ja	□ nein
Halluzinationen/Wahnvorstellungen		□ ja	□ nein
Weiteres: Wenn „ja", welche:		□ ja	□ nein
Psychopharmaka Wenn „ja", welche:		□ ja	□ nein

Augen

Sehstörung Wenn „ja", welche:		□ ja	□ nein
Seheinschränkung Wenn „ja", welche:		□ ja	□ nein
Art der Sehhilfe			
Stärke der Sehhilfe			

Doppelbilder	□ ja	□ nein
Lichtempfindlichkeit/-scheuheit	□ ja	□ nein

Weiteres:
Wenn „ja“, welche:

Bewegungsapparat

Schmerzen	□ ja	□ nein

Wenn „ja“, welche:

Schwäche	□ ja	□ nein
Steifigkeit	□ ja	□ nein
Rückenprobleme	□ ja	□ nein

Weiteres (auch Verlust von Körperteilen):

Bei Problemen mit dem Ausfüllen wenden Sie sich bitte an die studienbegleitenden Mitarbeiterinnen und Mitarbeiter!