frontiers

Supplementary Material

Author Statement

This document features supplemental material referred to in the scientific publication:

Reski N, Alissandrakis A and Kerren A (2021) An Empirical Evaluation of Asymmetric Synchronous Collaboration Combining Immersive and Non-Immersive Interfaces Within the Context of Immersive Analytics. *Front. Virtual Real.* 2:743445. doi: 10.3389/frvir.2021.743445

1 SPATIO-TEMPORAL COLLABORATION QUESTIONNAIRE

The questionnaire, as provided to the user study participants, is included in Figures S1 and S2.

2 OTHER STUDY MATERIAL

2.1 Study Scenario

The instructions for the user study, as provided to the participants, are included in Figure S3.

2.2 Answer and Observation Sheets

The answer sheet, as provided to the non-immersive interface users, for the fruits scenario is included in Figure S4 and for the veggies scenario in Figure S5. The observation sheet used by the non-immersive interface user to write down any worthwhile notes is included in Figure S6.

3 SUPPLEMENTARY ANALYSIS

3.1 Audio Activity Analysis

Separate audio stream recordings of the participant pair were processed using Audacity and its *Sound Finder* tool (with default settings) to determine when the participants were speaking during their sessions. Figures S7 to S16 visualize this verbal activity. Furthermore, system log data were processed to determine when the two users shared the same context (were at the same location at the same time in both interfaces), and this information is additionally visualized and included in each figure.

3.2 Pathway Visualization

Figures S17 to S21 show the pathway visualizations illustrating the spatial exploration of both users, i.e., location movements, over time (3D) for all task sessions. An interactive version of all pathway visualizations is available online as a web application: vrxar.lnu.se/apps/2021-frivr/.

Synchronous Asymmetric Interaction within the Context of Collaborative Immersive Analytics

Questionnaire: Collaboration

Instructions: For each of the following dimensions **[TSIA, NC, SC, AO]**, read carefully its definition, and for the questions / statements, mark *one* box that best describes your reactions to the tested application today.

Application

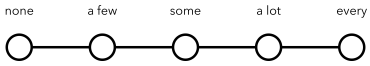
☐ Virtual Reality Application.
☐ Desktop Application.

Session

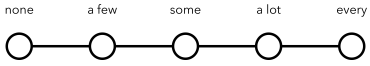
Date/Time: _____
Task: ☐ Fruits ☐ Vegetables

[TSIA] Transitions between Shared and Individual Activities: The interplay between individual and group efforts, including the ability to switch between these, within the scope of collaborative work.

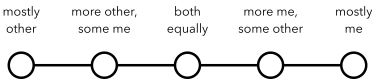
TSIA.1 How many of your efforts during this task would you consider to have been *individual* efforts?



TSIA.2 How many of your efforts during this task would you consider to have been *group* efforts?

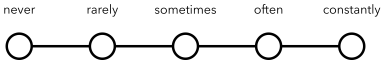


TSIA.3 According to your impression, who was more in a leading / directing role during the *group* efforts?

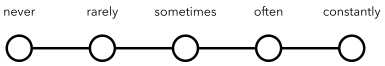


[NC] Negotiation and Communication: Verbal conversation (i.e., talk) facilitated through the ability of utilizing nonverbal information cues in order to discuss and interpret any task-related aspects of the activity (e.g., findings in the data, roles and structure of task approach, and so on).

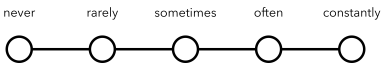
NC.1 According to your impression, how often did you communicate *verbally* to your partner?



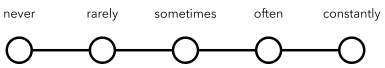
NC.2 According to your impression, how often did you communicate *nonverbally* to your partner?



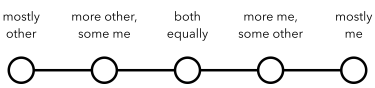
NC.3 How often would you consider did *dialog* take place?



NC.4 How often would you consider did *negotiation* take place?



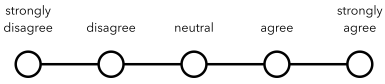
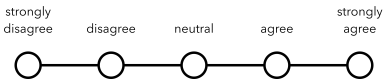
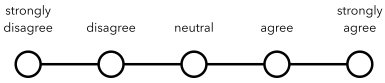
NC.5 Who would you say mostly initiated the *negotiations*?



Please continue on the next page.

Figure S1. Page 1 of the Spatio-Temporal Collaboration Questionnaire as presented to the participants in our user interaction study.

[SC] Sharing Context: Characteristics and features of the shared space that facilitate and support focused and unfocused collaborative work, leading to shared understandings.

SC.1	The collaborative features of the system allowed me to focus on the same subject as my partner.	
SC.2	The collaborative features of the system allowed me to establish a dialog with my partner.	
SC.3	The collaborative features of the system distracted me from my *individual* efforts.	

[AO] Awareness of Others: The ability to understand your partner's activity during times of (1) focused collaboration and active communication (i.e., *group* efforts), as well as (2) more independent and *individual* work.

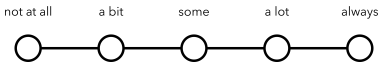
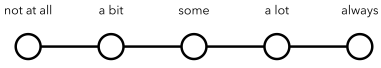
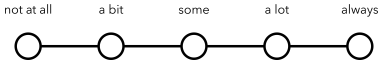
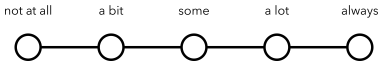
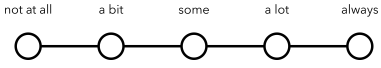
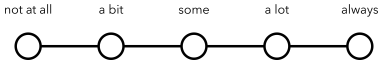
AO.1	During your *group* efforts, how much were you aware of your partner's activities?	
AO.2	During your *group* efforts, how much were you aware of your partner's location in space?	
AO.3	During your *group* efforts, how much were you aware of your partner's time reference (time point / interval)?	
AO.4	During your *individual* efforts, how much were you aware of your partner's activities?	
AO.5	During your *individual* efforts, how much were you aware of your partner's location in space?	
AO.6	During your *individual* efforts, how much were you aware of your partner's time reference (time point / interval)?	

Figure S2. Page 2 of the Spatio-Temporal Collaboration Questionnaire as presented to the participants in our user interaction study.

Disclaimer: The presented scenario and task are fictional, and have been exclusively created for the study you are participating in.

Scenario: It is the year 2X42. A series of scientific and technological advances made it possible to travel through the quantum realm. The exploration of many different variants of our dear Mother Earth followed in the years after. You are a two-person science team responsible for one such expedition. While one of you specializes on the collection and analysis of weather data, such as for instance sunlight and humidity levels, the other is an expert in the study and observation of plants, such as different types of fruits and vegetables.

After a joint excursion through the quantum realm during which you collected 150 days worth of data from different locations all over, what appears to be, the European landmass, you are now back in your research lab. Using the (non-immersive) weather terminal as well as the (immersive) plant exploration environment, you are ready to together take a closer look and make sense of your collected data.

Task: Your superintendent asked you for a report on the collected data. Collaboratively explore the collected weather and plant data in space and time, and use the provided tools to make assessments that describe the relationship between each plant and the two weather variables (sunlight and humidity). In short, based on your observations, determine the type of correlation between each weather and plant data, and additionally indicate how confident you are with those assessments. To support your conclusions, you should better write down noteworthy observations along the way.

Further Information:

- A correlation refers to the relationship between two variables.
- A positive correlation indicates that when one variable is increasing, the other variable is increasing as well. Or, when one variable is decreasing, the other variable is decreasing as well.
- A negative correlation indicates that when one variable is increasing, the other variable is decreasing (and vice versa).
- No correlation would indicate that when one variable is increasing, the other might be increasing, decreasing, or remain unchanged with equal probability.
- If you cannot determine the type of correlation based on your observations, please indicate so.
- You can assume that the location does not affect the correlations. A relationship between a weather variable and a plant would be the same across the planet, no matter the specific geographic location.

1

Figure S3. The instruction page with the scenario task provided to the study participants.

Synchronous Asymmetric Interaction within the context of Collaborative Immersive Analytics

Session - Date / Time: _____

Correlation: Based on your joint data exploration, please make assessments that describe the relationship between *fruit and sunlight*, as well as *fruit and humidity*.
Confidence: How *sure / confident* are you with your correlation assessment?

	Sunlight		**Humidity**	
Fruit	*Correlation*	*Confidence*	*Correlation*	*Confidence*
Apples	▫ Positive ▫ None ▫ Negative	▫ Do not know ▫ Low ▫ Medium ▫ High	▫ Positive ▫ None ▫ Negative	▫ Do not know ▫ Low ▫ Medium ▫ High
Oranges	▫ Positive ▫ None ▫ Negative	▫ Do not know ▫ Low ▫ Medium ▫ High	▫ Positive ▫ None ▫ Negative	▫ Do not know ▫ Low ▫ Medium ▫ High
Bananas	▫ Positive ▫ None ▫ Negative	▫ Do not know ▫ Low ▫ Medium ▫ High	▫ Positive ▫ None ▫ Negative	▫ Do not know ▫ Low ▫ Medium ▫ High
Berries	▫ Positive ▫ None ▫ Negative	▫ Do not know ▫ Low ▫ Medium ▫ High	▫ Positive ▫ None ▫ Negative	▫ Do not know ▫ Low ▫ Medium ▫ High
Grapes	▫ Positive ▫ None ▫ Negative	▫ Do not know ▫ Low ▫ Medium ▫ High	▫ Positive ▫ None ▫ Negative	▫ Do not know ▫ Low ▫ Medium ▫ High

Note: Once both of you agree that you have finished your joint data exploration, please say aloud "*We are done with the data exploration.*"

Figure S4. The answer sheet provided to the non-immersive desktop interface participant to write down the correlations (for the fruits scenario).

Synchronous Asymmetric Interaction within the context of Collaborative Immersive Analytics

Session - Date / Time: _____

Correlation: Based on your joint data exploration, please make assessments that describe the relationship between *vegetable and sunlight*, as well as *vegetable and humidity*.
Confidence: How *sure / confident* are you with your correlation assessment?

	Sunlight		**Humidity**	
Vegetable	*Correlation*	*Confidence*	*Correlation*	*Confidence*
Tomatoes	▢ Positive ▢ None ▢ Negative	▢ Do not know ▢ Low ▢ Medium ▢ High	▢ Positive ▢ None ▢ Negative	▢ Do not know ▢ Low ▢ Medium ▢ High
Carrots	▢ Positive ▢ None ▢ Negative	▢ Do not know ▢ Low ▢ Medium ▢ High	▢ Positive ▢ None ▢ Negative	▢ Do not know ▢ Low ▢ Medium ▢ High
Potatoes	▢ Positive ▢ None ▢ Negative	▢ Do not know ▢ Low ▢ Medium ▢ High	▢ Positive ▢ None ▢ Negative	▢ Do not know ▢ Low ▢ Medium ▢ High
Cabbages	▢ Positive ▢ None ▢ Negative	▢ Do not know ▢ Low ▢ Medium ▢ High	▢ Positive ▢ None ▢ Negative	▢ Do not know ▢ Low ▢ Medium ▢ High
Lettuces	▢ Positive ▢ None ▢ Negative	▢ Do not know ▢ Low ▢ Medium ▢ High	▢ Positive ▢ None ▢ Negative	▢ Do not know ▢ Low ▢ Medium ▢ High

Note: Once both of you agree that you have finished your joint data exploration, please say aloud "*We are done with the data exploration.*"

Figure S5. The answer sheet provided to the non-immersive desktop interface participant to write down the correlations (for the vegetables scenario).

Synchronous Asymmetric Interaction within the context of Collaborative Immersive Analytics

Session - Date / Time: _____

Noteworthy Observations

Location	Time Event / Time Range	Plant	Sunlight	Humidity
Japan	day 23 - day 42	Rice	▣	▢
New Zealand	day 45	Kiwis	▢	▣
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢
			▢	▢

Figure S6. The sheet provided to the non-immersive desktop interface participant to note any observations (one copy for each scenario). The example locations and plants deliberately do not belong to any scenario datasets.

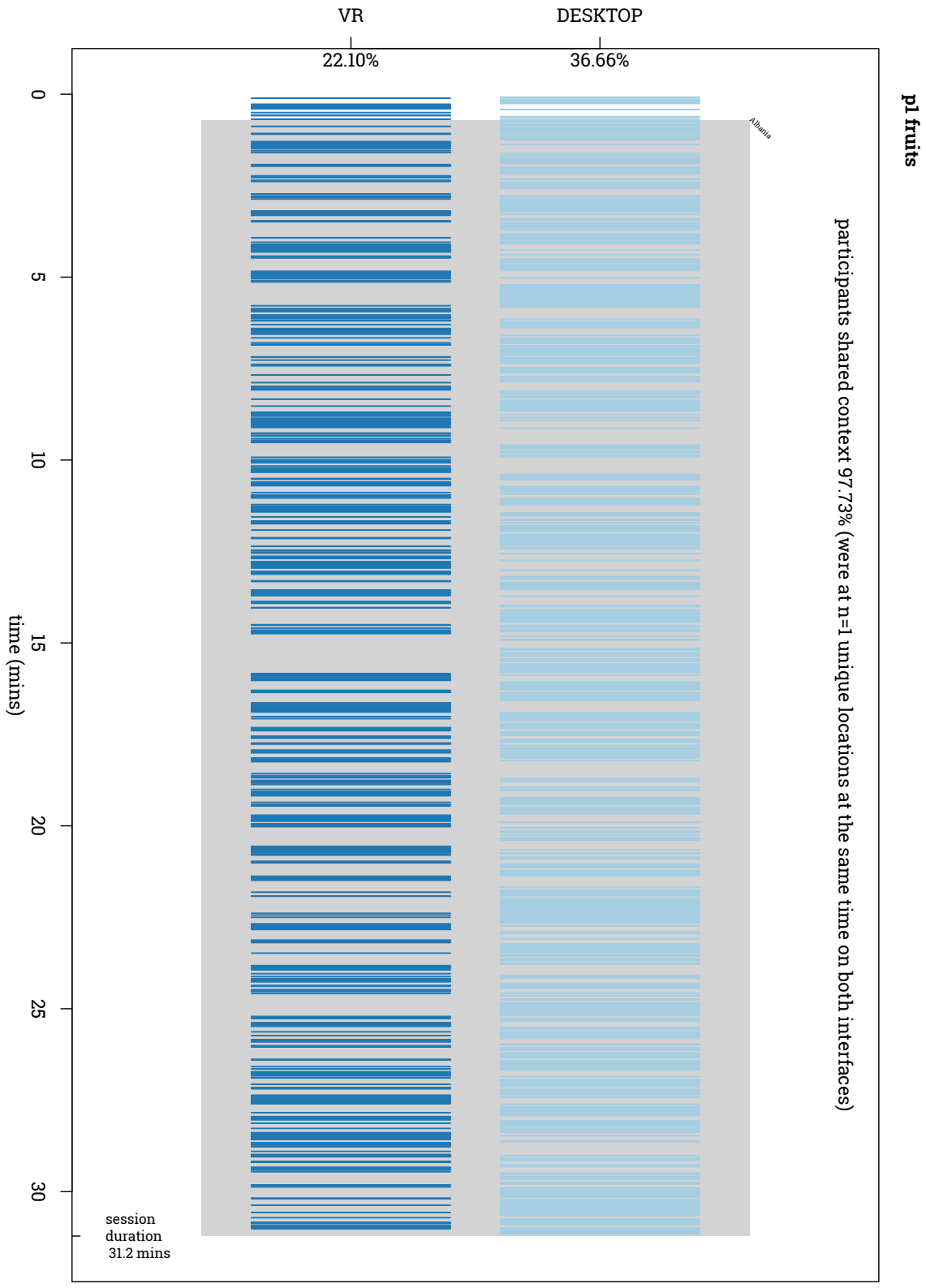


Figure S7. Audio activity and shared context analysis for the pair p1, fruits scenario. Dark and light blue rectangles indicate the detected audio activity by the immersive and non-immersive interface users, respectively. The shaded rectangles indicate that the participants were sharing the same context (were at the same location at the same time in both interfaces).

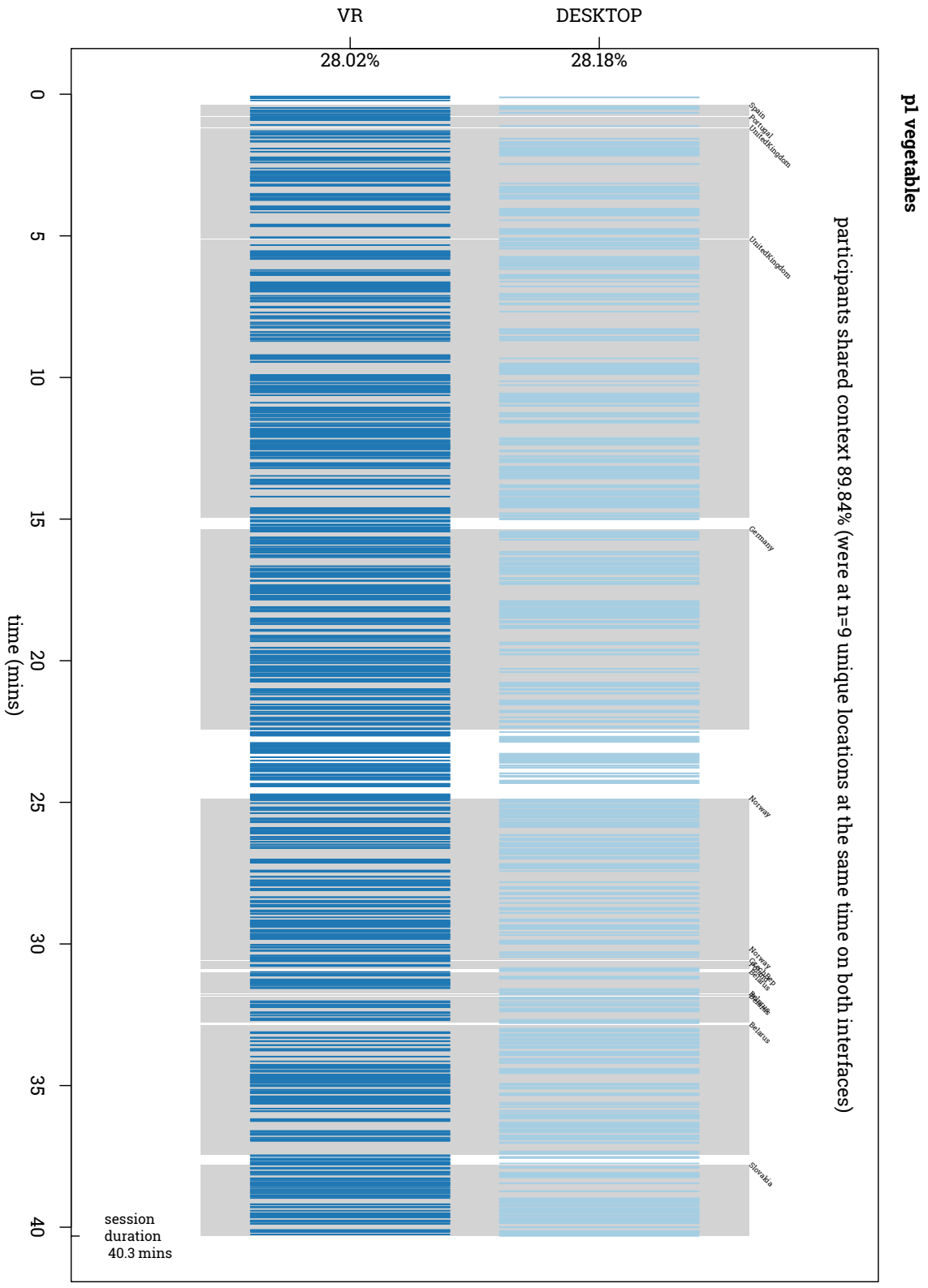


Figure S8. Audio activity and shared context analysis for the pair p1, veggies scenario. Dark and light blue rectangles indicate the detected audio activity by the immersive and non-immersive interface users, respectively. The shaded rectangles indicate that the participants were sharing the same context (were at the same location at the same time in both interfaces).

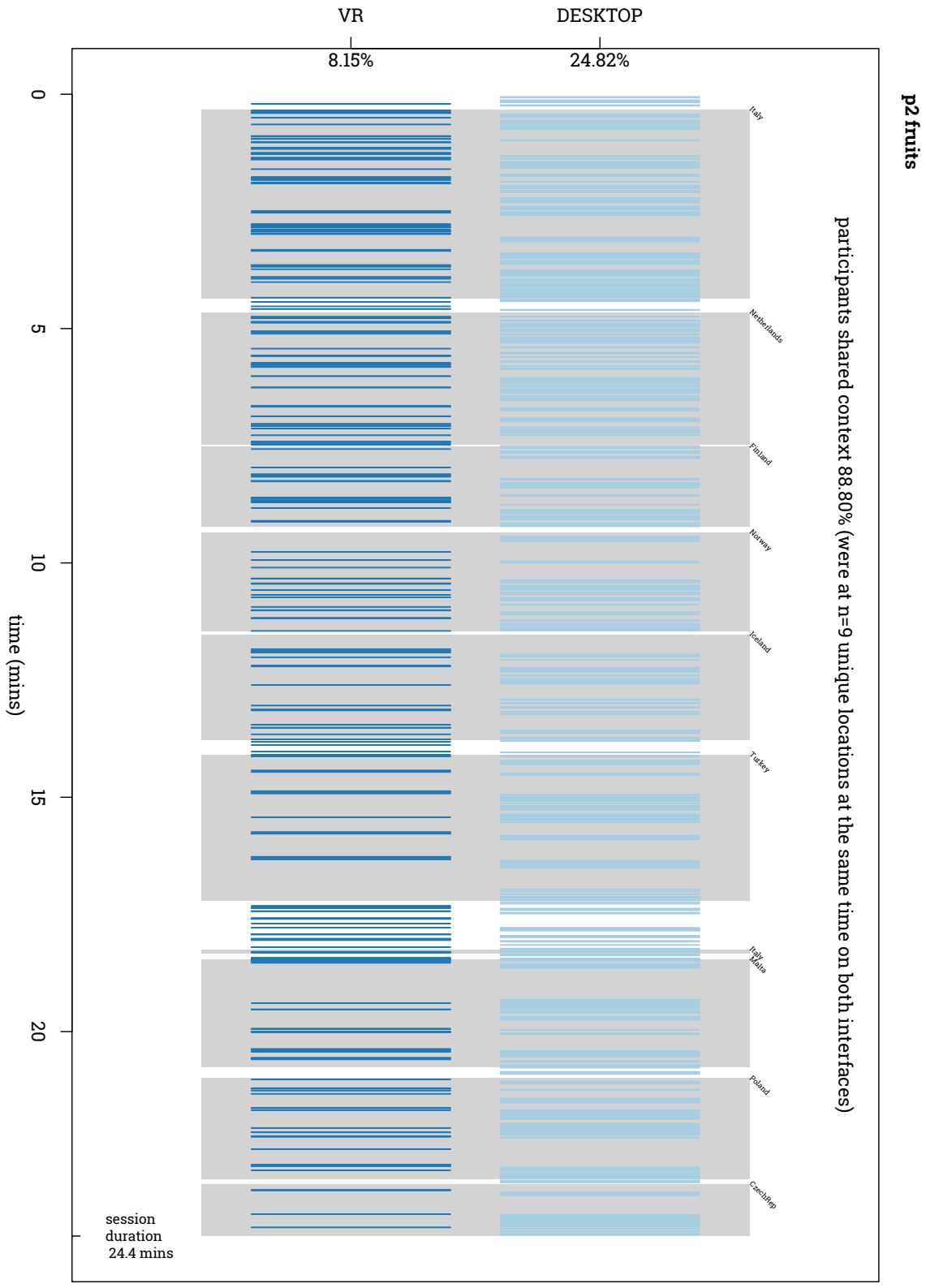


Figure S9. Audio activity and shared context analysis for the pair p2, fruits scenario. Dark and light blue rectangles indicate the detected audio activity by the immersive and non-immersive interface users, respectively. The shaded rectangles indicate that the participants were sharing the same context (were at the same location at the same time in both interfaces).

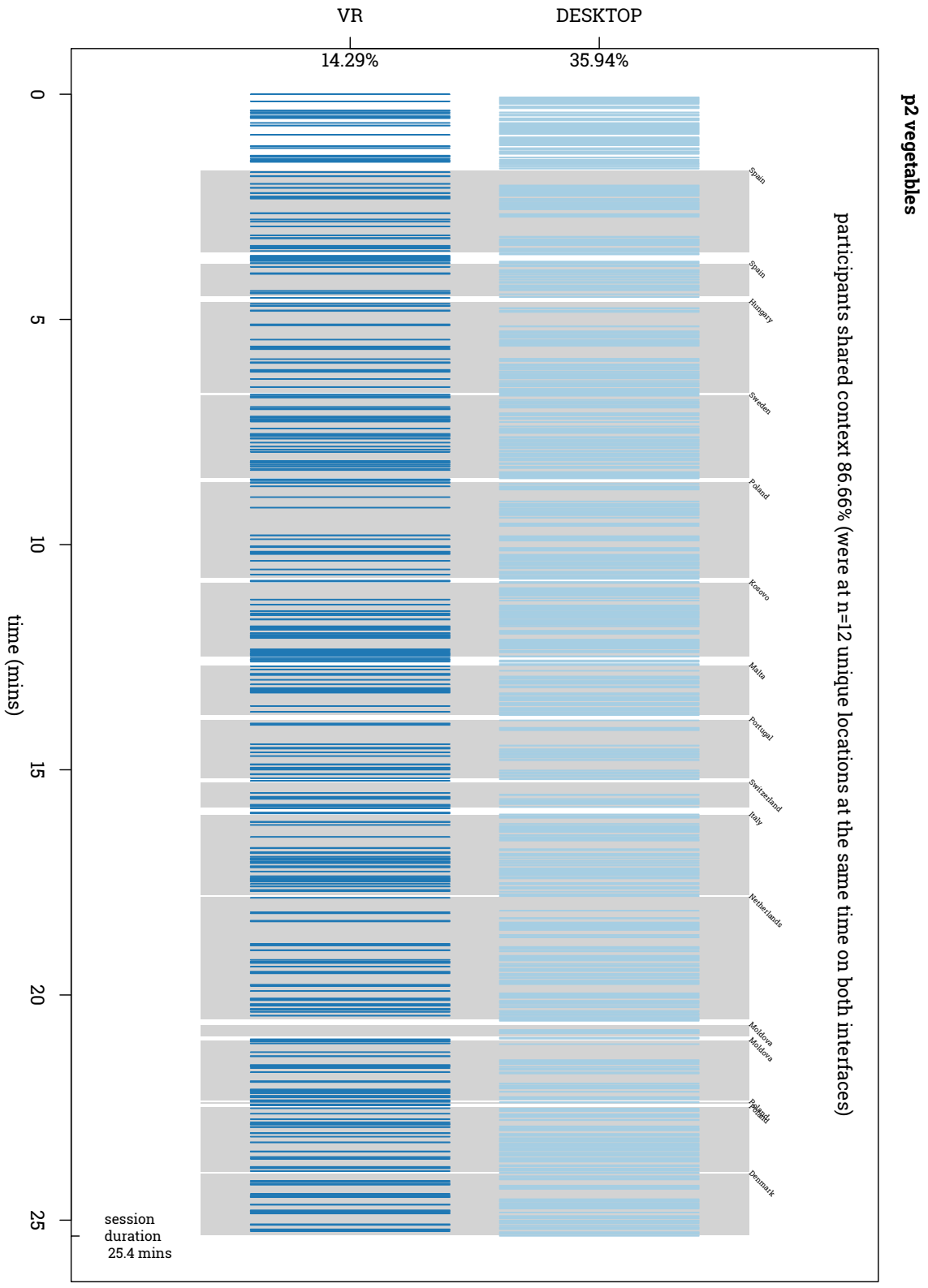


Figure S10. Audio activity and shared context analysis for the pair p2, veggies scenario. Dark and light blue rectangles indicate the detected audio activity by the immersive and non-immersive interface users, respectively. The shaded rectangles indicate that the participants were sharing the same context (were at the same location at the same time in both interfaces).

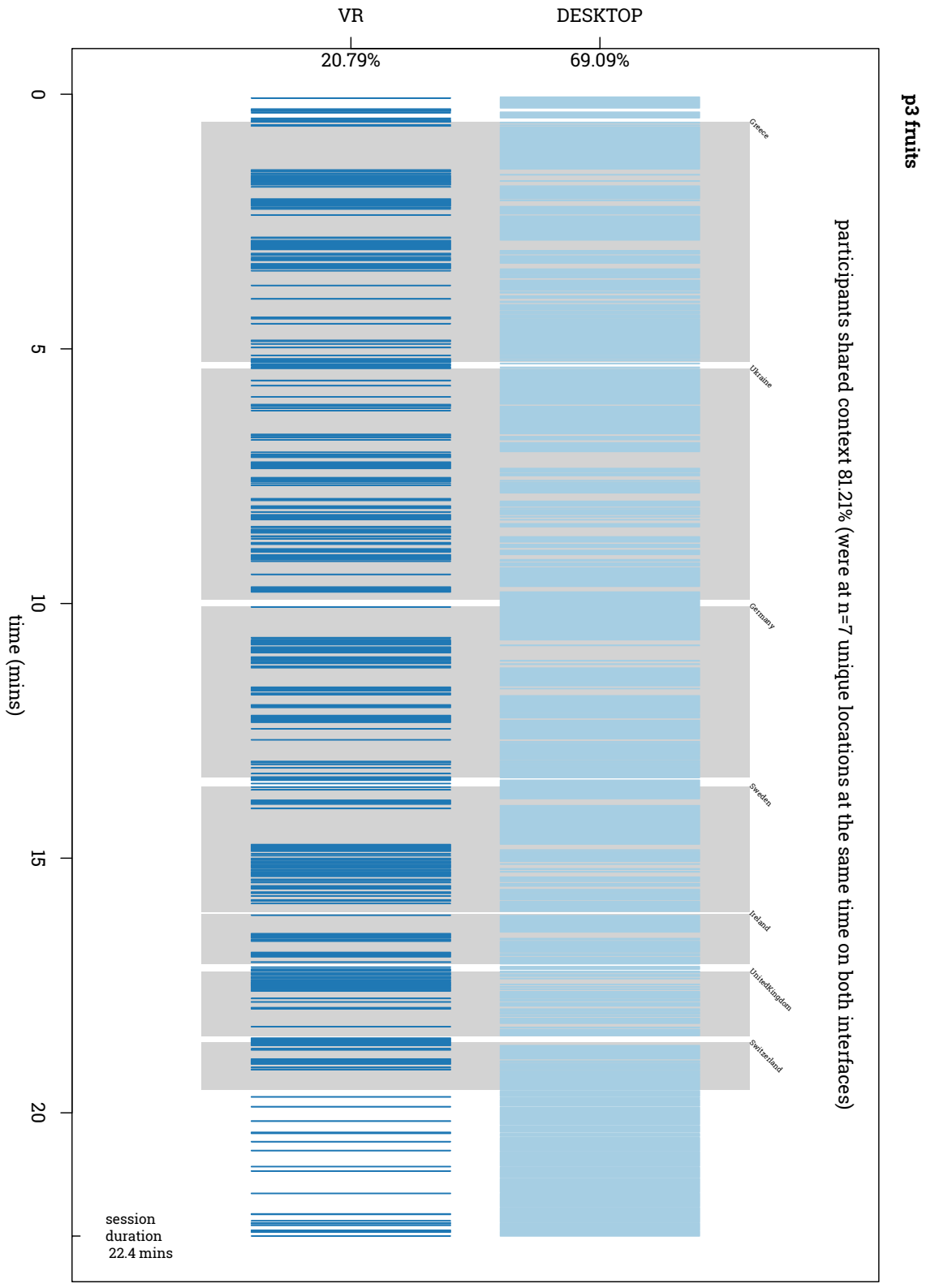


Figure S11. Audio activity and shared context analysis for the pair p3, fruits scenario. Dark and light blue rectangles indicate the detected audio activity by the immersive and non-immersive interface users, respectively. The shaded rectangles indicate that the participants were sharing the same context (were at the same location at the same time in both interfaces).

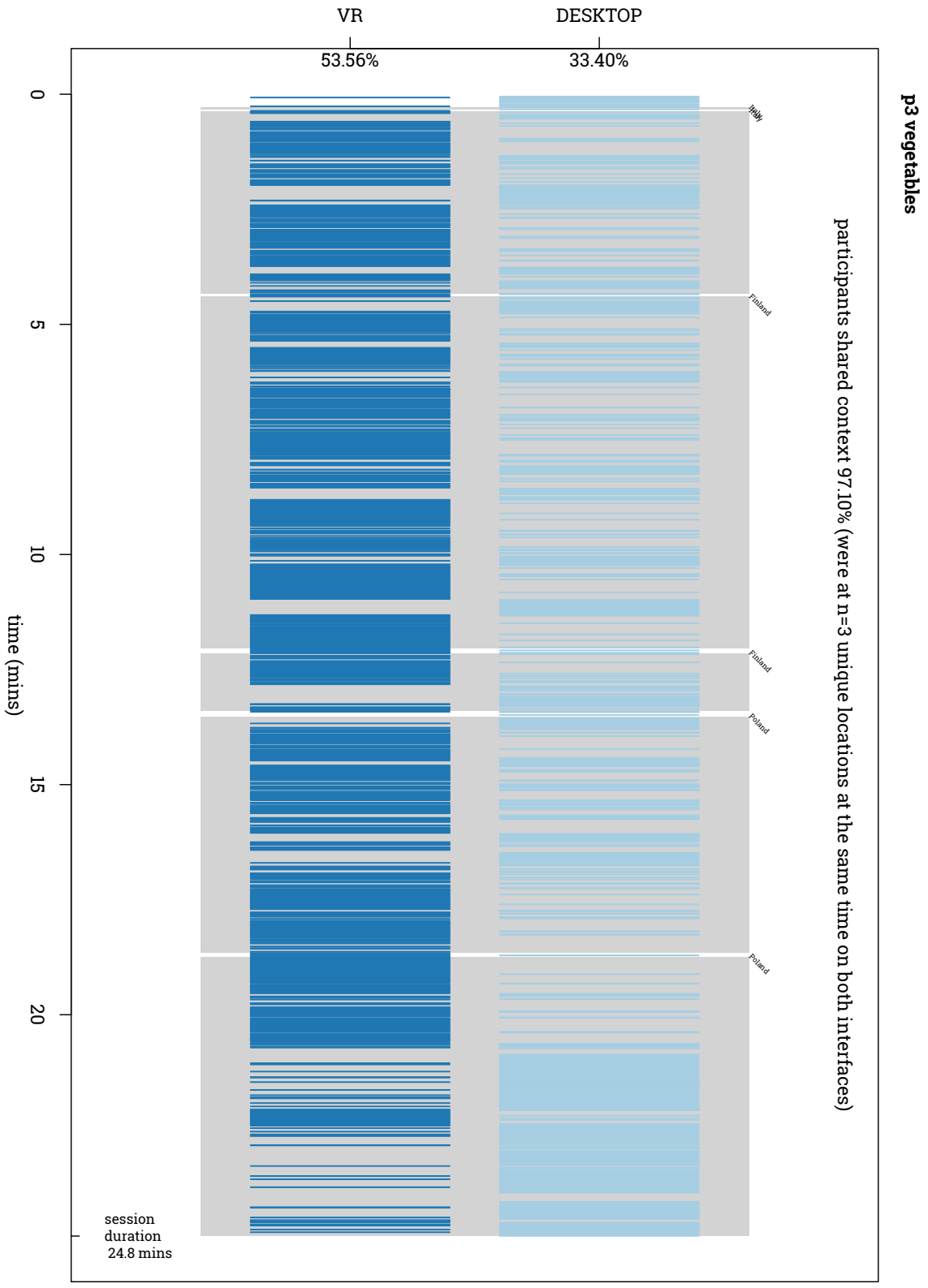


Figure S12. Audio activity and shared context analysis for the pair p3, veggies scenario. Dark and light blue rectangles indicate the detected audio activity by the immersive and non-immersive interface users, respectively. The shaded rectangles indicate that the participants were sharing the same context (were at the same location at the same time in both interfaces).

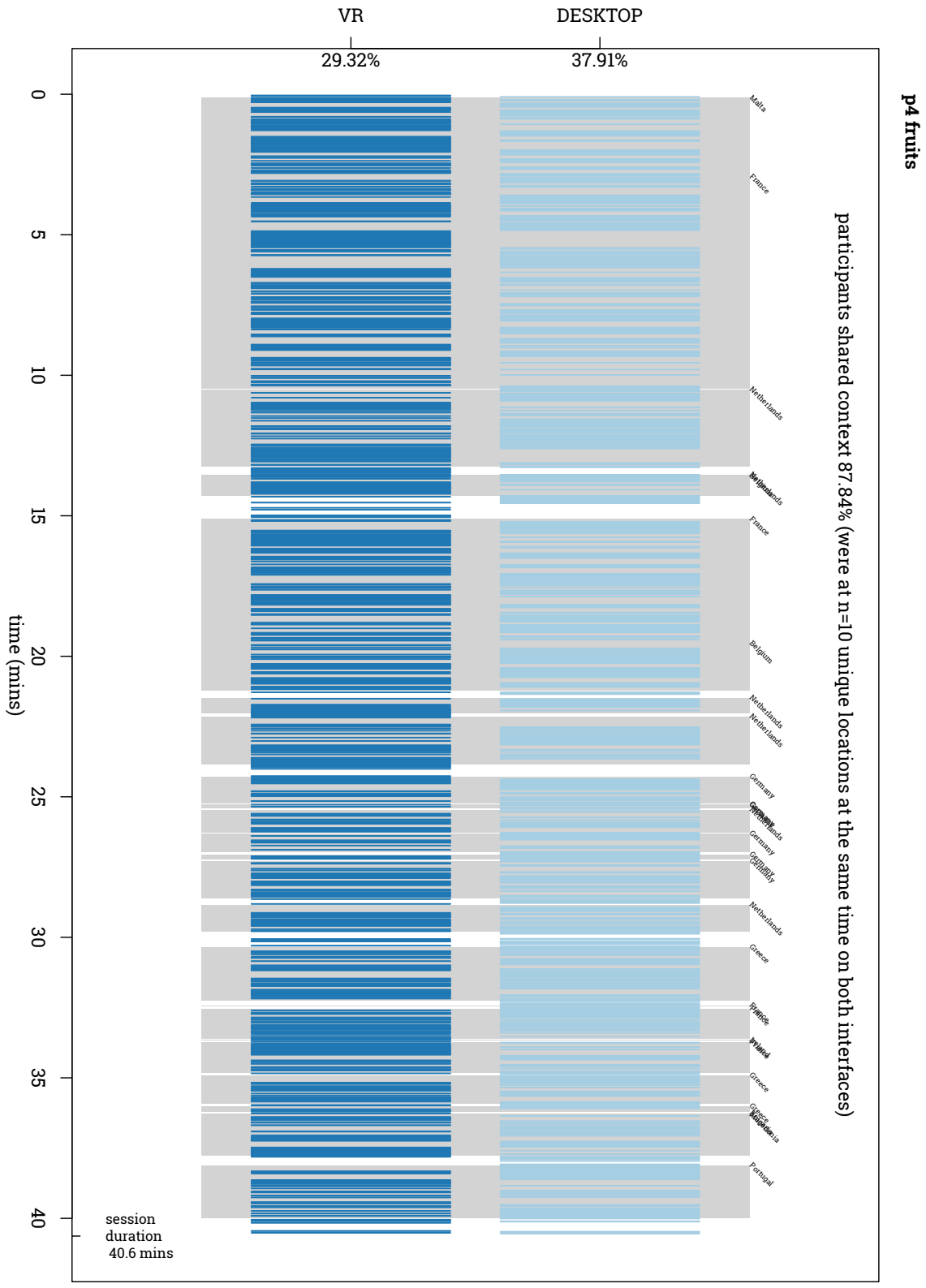


Figure S13. Audio activity and shared context analysis for the pair p4, fruits scenario. Dark and light blue rectangles indicate the detected audio activity by the immersive and non-immersive interface users, respectively. The shaded rectangles indicate that the participants were sharing the same context (were at the same location at the same time in both interfaces).

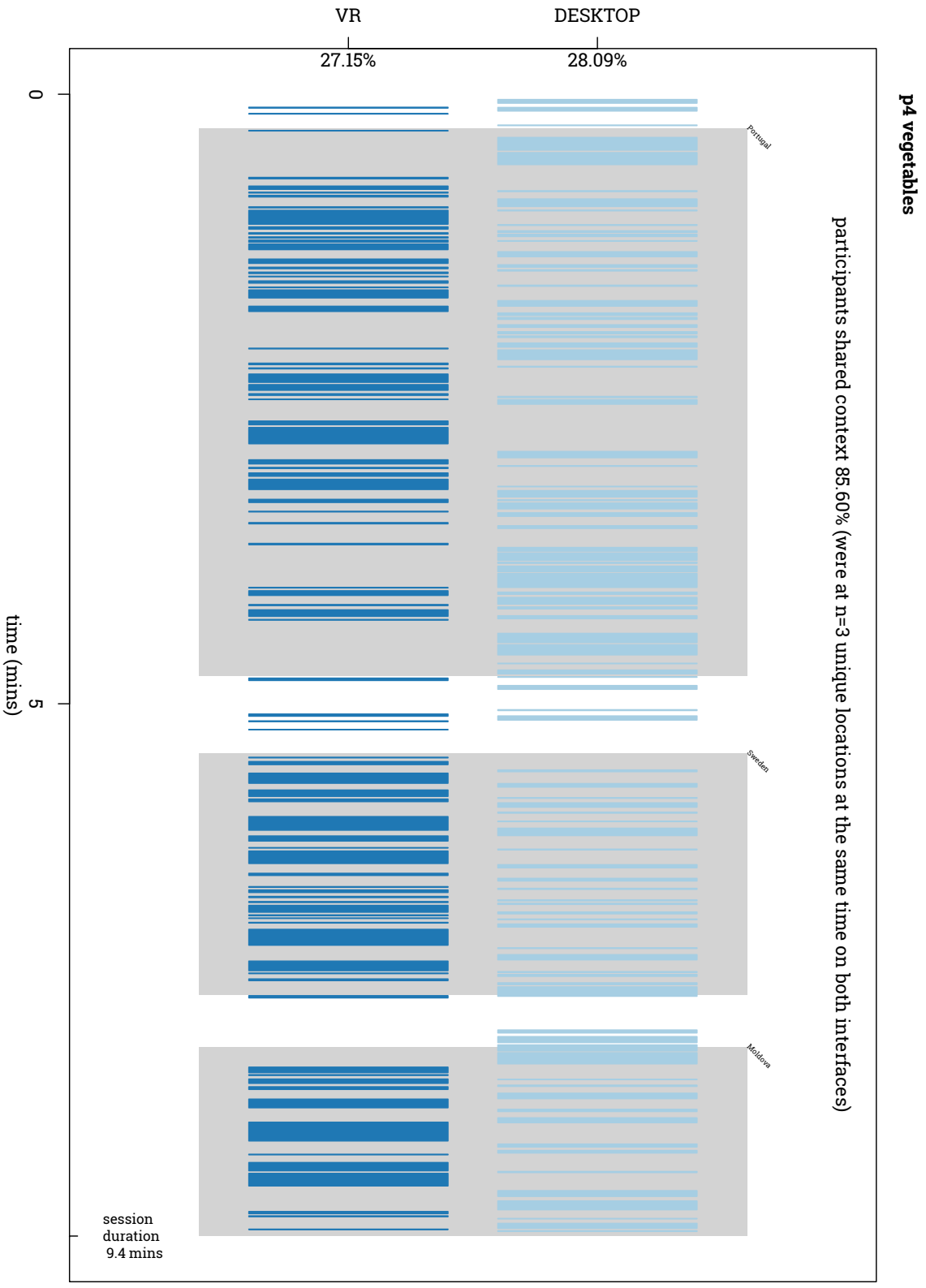


Figure S14. Audio activity and shared context analysis for the pair p4, veggies scenario. Dark and light blue rectangles indicate the detected audio activity by the immersive and non-immersive interface users, respectively. The shaded rectangles indicate that the participants were sharing the same context (were at the same location at the same time in both interfaces).

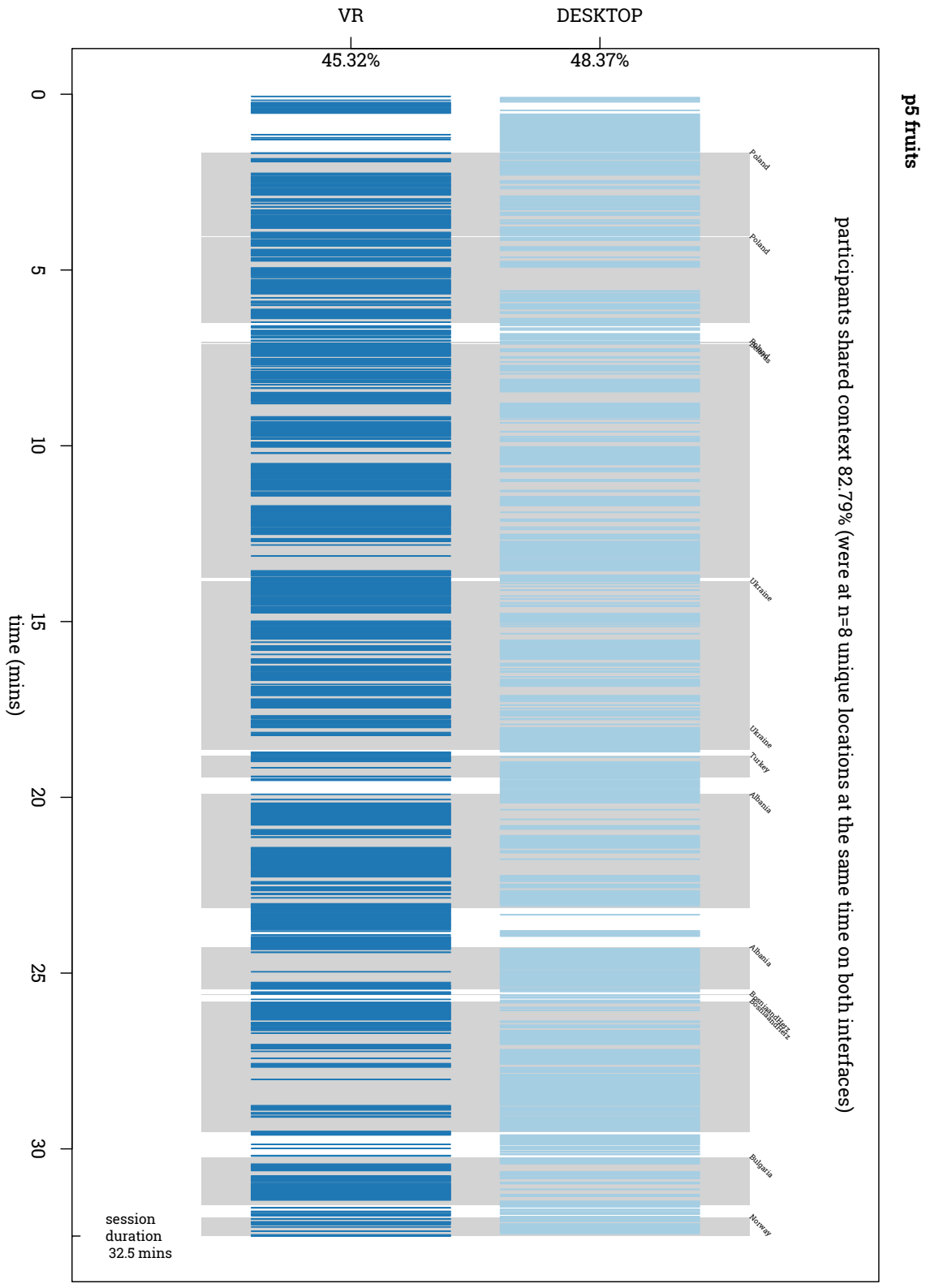


Figure S15. Audio activity and shared context analysis for the pair p5, fruits scenario. Dark and light blue rectangles indicate the detected audio activity by the immersive and non-immersive interface users, respectively. The shaded rectangles indicate that the participants were sharing the same context (were at the same location at the same time in both interfaces).

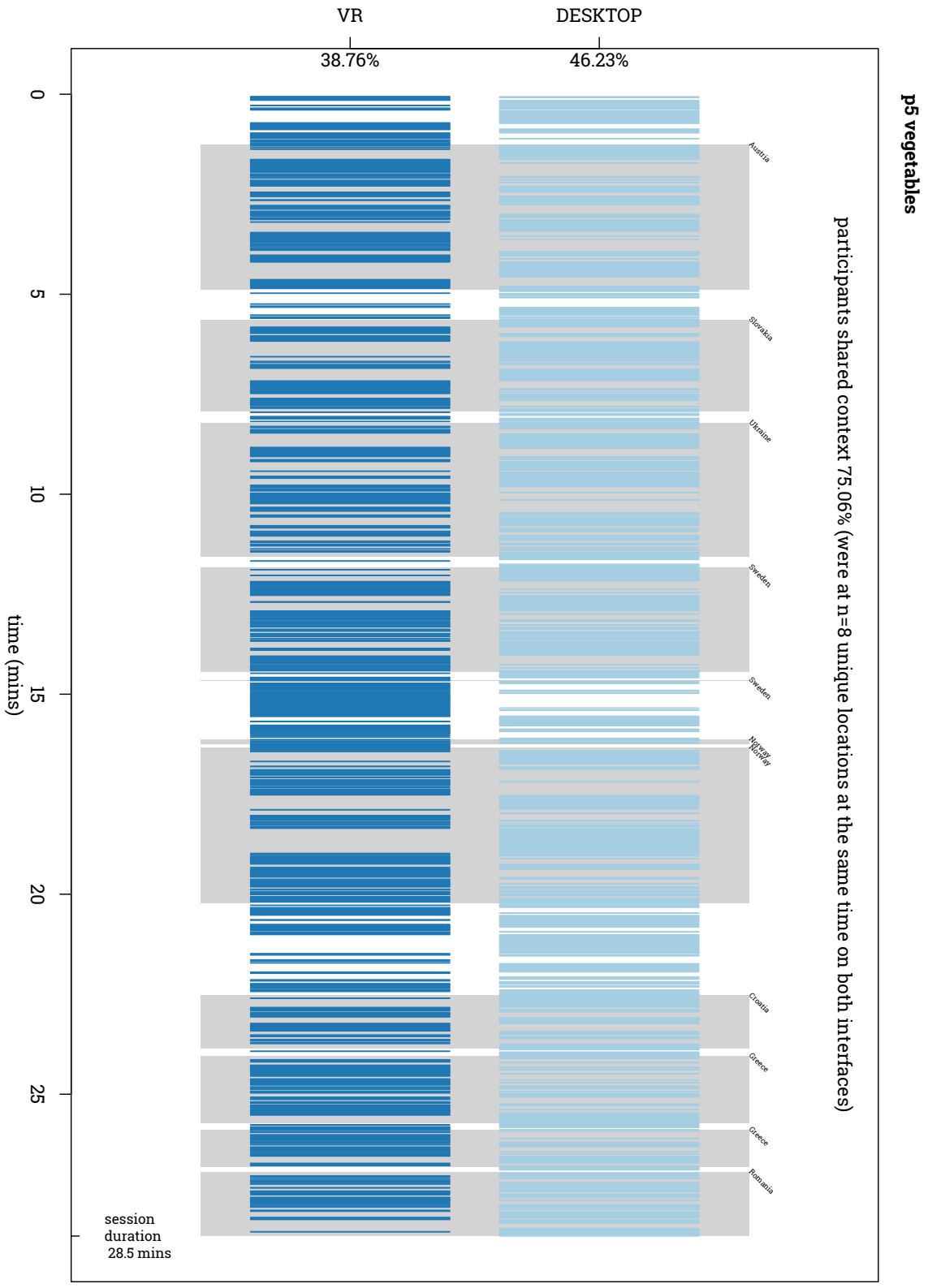


Figure S16. Audio activity and shared context analysis for the pair p5, veggies scenario. Dark and light blue rectangles indicate the detected audio activity by the immersive and non-immersive interface users, respectively. The shaded rectangles indicate that the participants were sharing the same context (were at the same location at the same time in both interfaces).

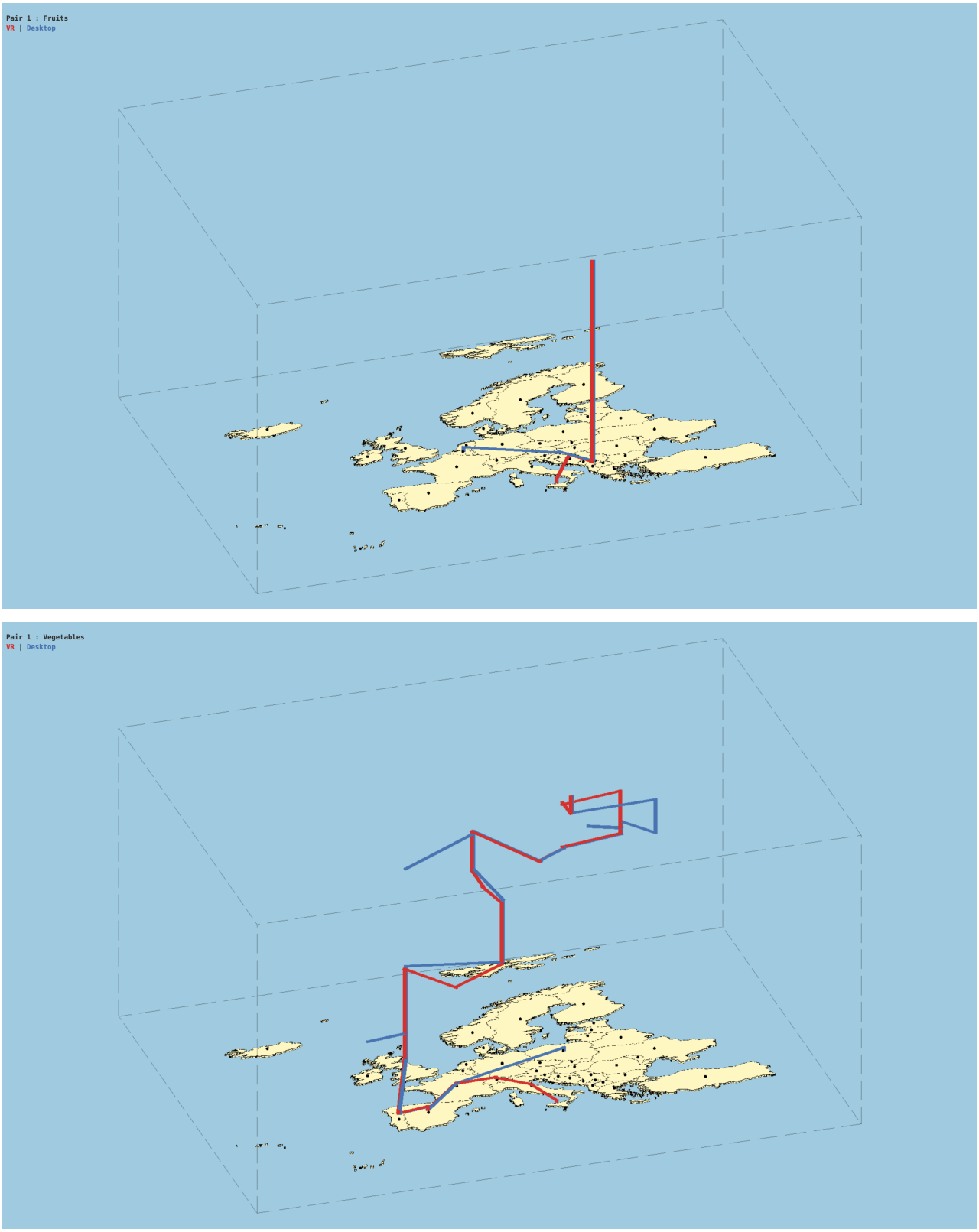


Figure S17. Pathway visualization for pair p1, fruits scenario (top), veggies scenario (bottom). The red pathway represents the immersive interface user (VR), while the blue pathway represents the non-immersive interface user (desktop). Online interactive versions at vrxar.lnu.se/apps/2021-frivr/?id=p1f and vrxar.lnu.se/apps/2021-frivr/?id=p1v respectively.

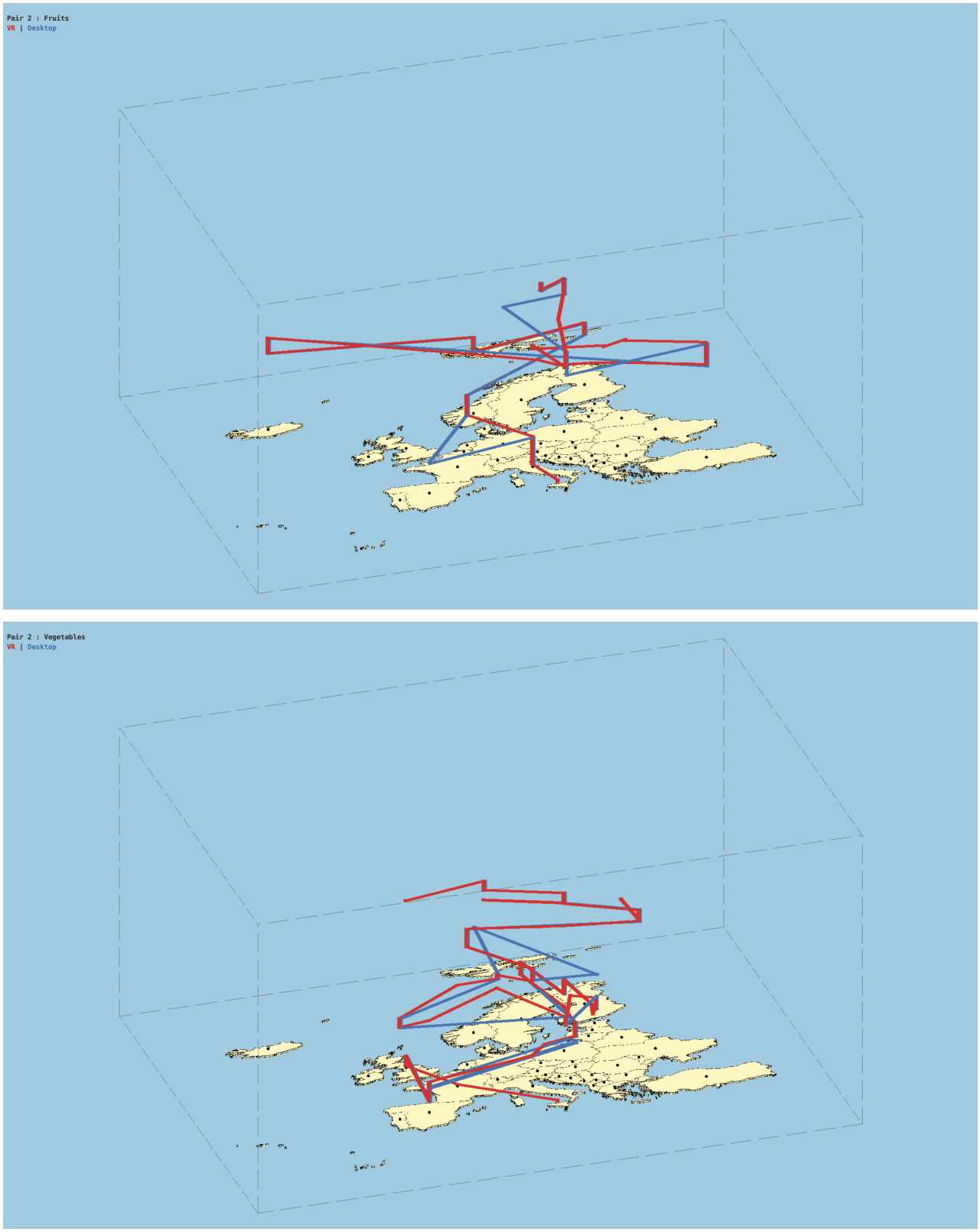


Figure S18. Pathway visualization for pair p2, fruits scenario (top), veggies scenario (bottom). The red pathway represents the immersive interface user (VR), while the blue pathway represents the non-immersive interface user (desktop). Online interactive versions at vrxar.lnu.se/apps/2021-frivr/?id=p2f and vrxar.lnu.se/apps/2021-frivr/?id=p2v respectively.

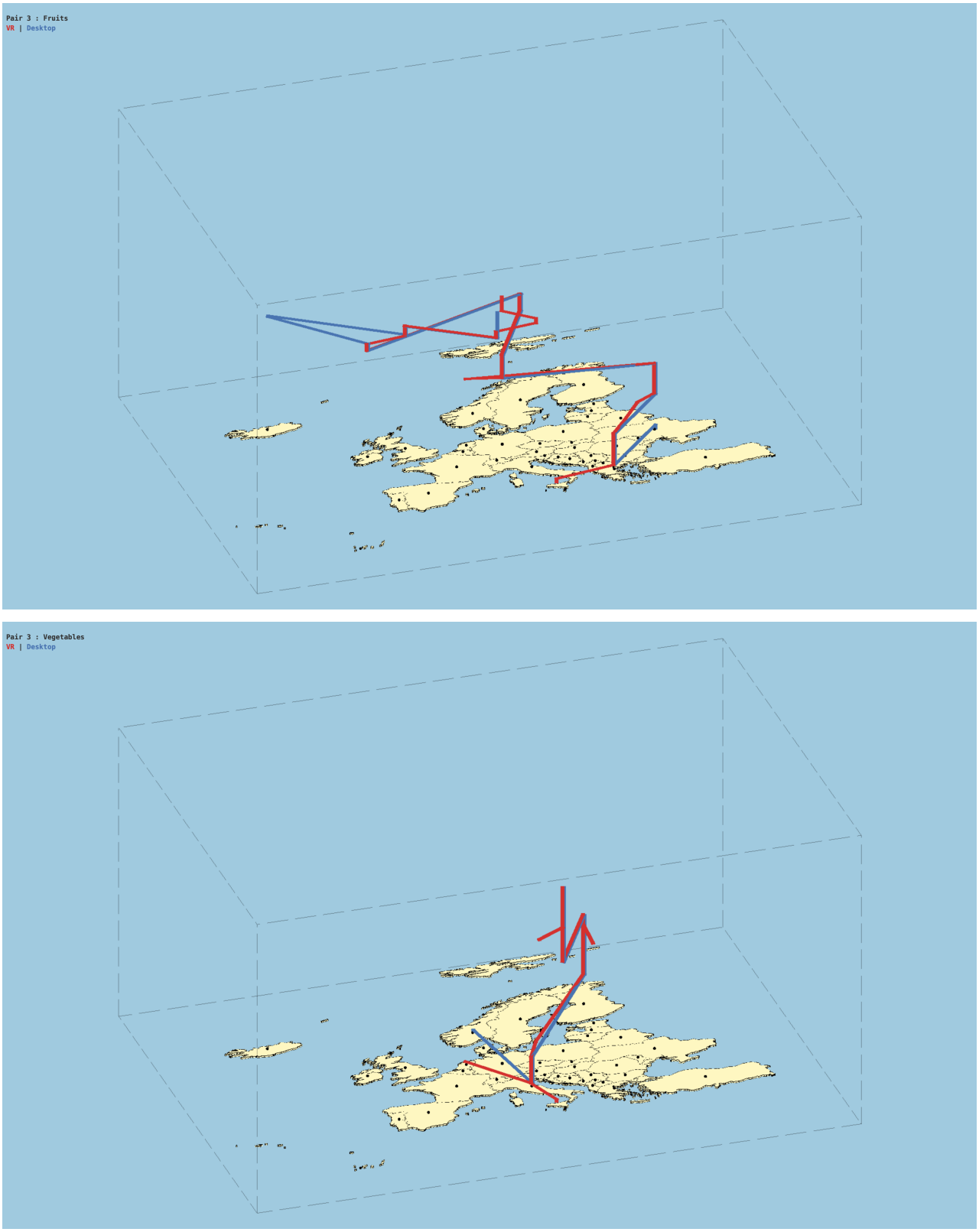


Figure S19. Pathway visualization for pair p3, fruits scenario (top), veggies scenario (bottom). The red pathway represents the immersive interface user (VR), while the blue pathway represents the non-immersive interface user (desktop). Online interactive versions at vrxar.lnu.se/apps/2021-frivr/?id=p3f and vrxar.lnu.se/apps/2021-frivr/?id=p3v respectively.

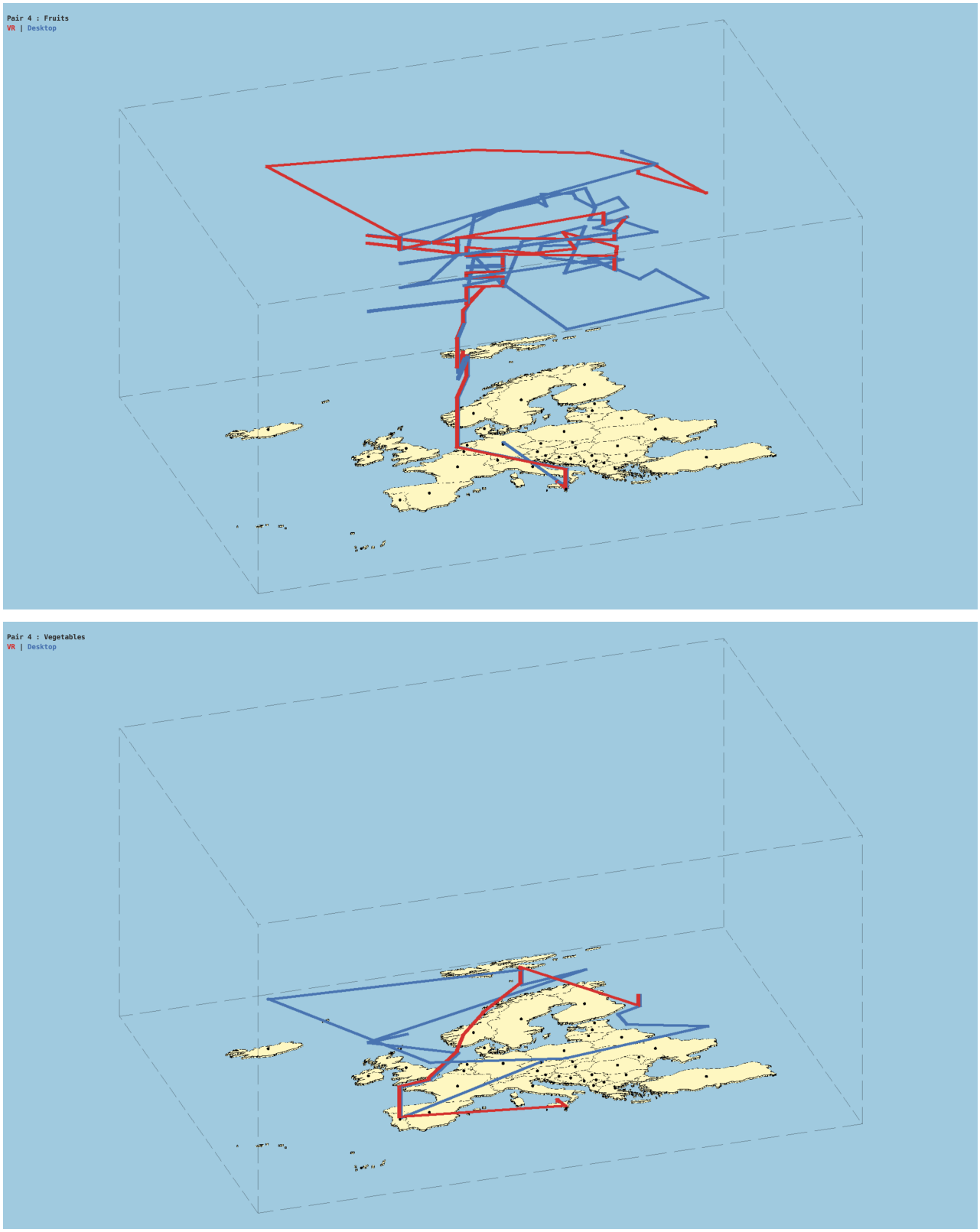


Figure S20. Pathway visualization for pair p4, fruits scenario (top), veggies scenario (bottom). The red pathway represents the immersive interface user (VR), while the blue pathway represents the non-immersive interface user (desktop). Online interactive versions at vrxar.lnu.se/apps/2021-frivr/?id=p4f and vrxar.lnu.se/apps/2021-frivr/?id=p4v respectively.

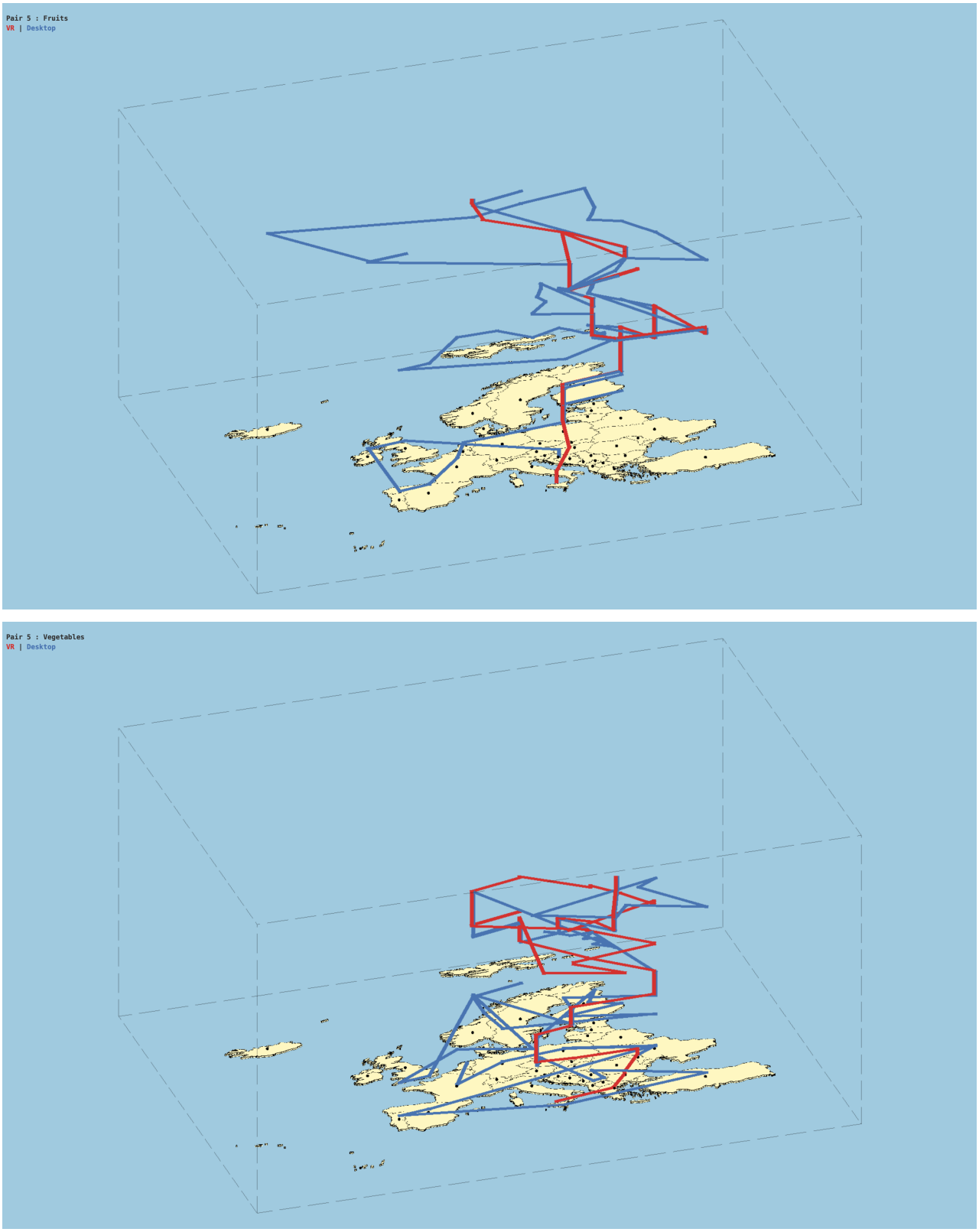


Figure S21. Pathway visualization for pair p5, fruits scenario (top), veggies scenario (bottom). The red pathway represents the immersive interface user (VR), while the blue pathway represents the non-immersive interface user (desktop). Online interactive versions at vrxar.lnu.se/apps/2021-frivr/?id=p5f and vrxar.lnu.se/apps/2021-frivr/?id=p5v respectively.