frail safe

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7.3.1	21/2/18	Preparation	Marina Kotsani (INSERM) Elena Aristodemou (MATERIA)	Protocol for activities' monitoring description and finalisation
7.3.2	19/3/18	Data collection	Anne Freminet (INSERM) Sibora-Rafaella Tsela (UoP) Maria Dimopoulou (UoP) Soteria Moza (MATERIA) Elena Aristodemou (MATERIA)	Data provided from clinical field studies
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EXECUTIVE SUMMARY

This report has been prepared in the context of Task 7.2. - Deployment of trail operation in semi-controlled environments of WP7.

It provides the results of a small-scale evaluation of the first version of the integrated system tested in real life environments. A small sample of the study's participants tested the ability of the signal analysis algorithms to automatically categorize the signals on the basis of older people's activities/characteristics and the sensitivity of the sensors.

In the first section the protocol of signal collection is provided, whereas in the second and third sections, results derived from beacons, GPS, WWBS and external independent IMUs respectively are discussed. The last section contains detail data presented in annexes.

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Abstract (for dissemination)	This document provides the results of a small-scale evaluation of the first version of the integrated system in real life environments. A cohort of 30 older people underwent a protocol related to mobility activities in order to test the ability of the signal analysis algorithms to automatically categorize the signals on the basis of older people activities and the sensitivity of the sensors with respect to different movements.			
Keywords	Movements, algorithms, activities, signal recognition.			

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List of abbreviations and acronyms (*in alphabetic order*)

acc	Accelerometer
ba	Breathing amplitude
br	Breathing rate
ecg	Electrocardiogram
GPS	Global Positioning System
gyro	gyroscope
hr	Heart rate
IMU	Inertial Measurement Unit
qel	Quartenion left
qer	Quartenion right
TUG	Timed get Up and Go
VPM	Virtual Patient Model
WP	Work Package
WWBS	Wearable WBAN System

1 Introduction

In achieving the aim of this small-scale report, the FrailSafe team tried to evaluate the ability of the developed system (WWBS, IMUs sensors, beacons, GPS) to identify mainly mobility-related activities, in simulated real-life environments.

For this purpose, 30 participants, 10 from each centre, have been selected to test the sensor-based system. The selection took place with convenience criteria, i.e. those participants, belonging to group B, who had their usual FrailSafe sessions programmed during the testing period (March 2018), according to the study's general time schedule (D2.1), without taking any special care for a given frailty status repartition. A structured intervention took place in semi-controlled environments, where participants executed a predefined battery of movements equipped with several FrailSafe devices.

The goal has been to test the ability of the signal analysis algorithms to automatically categorize the signals on the basis of older people's activities and characteristics and the sensitivity of the sensors with respect to different environmental conditions.

2 Activities' protocol

The small-scale evaluation has been conducted in all three clinical centres (France, Greece and Cyprus), where a selection of ten (10) seniors per country tested a part of the first integrated version of the FrailSafe system; WWBS, external independent IMUs, a set of beacons and a smart phone, by performing a predefined battery of physical activities, guided by a trained investigator.

Those specific activities have been chosen among standard tests of physical performance so as to enable the homogenous execution of the tasks all over 3 clinical centres to the maximum and to be correlated, if needed, to the corresponding tests performed during the clinical evaluation. During each of these activities, in between laps, time was kept and noted down.

The equipment used during these activities consisted of the WWBS system (with its incorporated IMUs), 5 independent external IMUs put on the right wrist, left wrist, left ankle, right ankle and lower waist area (3 for Patras for technical reasons), one beacon set, one smartphone with its GPS application, a FORA tension meter and a chronometer. The protocol followed was described in D7.2 (M26) and is presented in figure 1.

Figure 1: Protocol for signal testing

ID :	Date :	Start time (Smartphone) : __ :__	
LAPS	**Actions**	**Time (Chronometer)**	**Remarks**
-	Instructions: The participant is asked to cross the hands in front of his/her chest and not use them. If he/she needs to use hands to sit and stand, the clinician notes it in the remarks. The lap changes at the 6th sit.		
Lap 1	**5 times sit and stand**		
Lap 2	Instructions: The participant is asked to reach an item the clinician is holding. The distance should seem reachable but it shouldn't be.		(Dead time)
Reaching forward:			
Lap 3	• Sitting position		
Lap 4	Instructions: The participant is asked to lean forward and try to rich the wall. He/she is placed at a position that is not to close, but also not too far from the wall.		(Dead time)
Lap 5	• Standing position		
Lap 6	Instructions: The participant is asked to lift each leg and stay there for as long as he/she can.		(Dead time)
Standing on one single foot:			
Lap 7	• On right leg (5-10 sec)		
Lap 8	• On left leg (5- 10 sec)		
Lap 9	Instructions: The participant is asked to stand with legs levelled to the opening of the shoulders.		(Dead time)
Standing with normal pace width:			
Lap 10	• With open eyes (10 sec)		
Lap 11	• With closed eyes (10 sec)		
Lap 12	Instructions: The participant is asked to stand with the legs closed.		(Dead time)
Standing with joined pace width:			
Lap 13	• With open eyes (10 sec)		
Lap 14	• With closed eyes (10 sec)		

Lap 15	Instructions: The participant is asked to walk up to the sticker on the floor (3m away) and return. The lap changes when he/she sits.		(Dead time)
Lap 16	**Time get up and go**		
Lap 17	Instructions: The participant is asked to walk for 30 seconds up and down in the room.		(Dead time)
Lap 18	**Gait speed (30 sec walking up and down)**		
Lap 19	Instructions: The participant is asked to pick up an object from the floor, in any way they can.		(Dead time)
Lap 20	**Pick an object up from the floor**		
Lap 21	Instructions: The participant is asked to take 5 short breaths quickly.		(Dead time)
Lap 22	**5 breaths quickly**		
Lap 23	Instructions: The participant is asked to walk to another room and return. The lap starts when the participant starts walking and changes when he/she is back next to the clinician.		(Dead time)
Lap 24	**In and out of the room**		
Lap 25	Preparation for blood pressure taking. The lap starts when the start button of the BP is pressed and stops when the screen shows the heart rate.		(Dead time)
Lap 25	**Blood pressure measurement (note down the Heart Rate only)**		
		End time (Smartphone): __ : __	

In addition to this, participants were kindly asked to keep a calendar of their outdoor activities during a short period of three days, while carrying around at the same time the smart phone (figure 2) with the running GPS Logger app. This activity was proposed in order to be able to check if the information acquired from the GPS device is relevant. However, no specific outdoor activity was proposed to them, due to security and ethical reasons and the track keeping of their spontaneous activities was not obligatory to be completed.

Figure 2: Example of the outdoors activities' calendar

ACTIVITY	TIME	TRAVEL WAY	DISTANCE
Got out to buy bread	11.20-11.45am	On foot	200m or two blocks
Went to gym- aerobic	17.00-17.45pm	By car	about 700m from home

Last, participants were asked to note if they experienced any unusual event, feeling or symptom while wearing the devices, specifying on the time this has happened. No event of this type was reported during the monitoring period for the 30 individuals that participated in this small-scale evaluation protocol.

3 Results of signal analysis

Prior to results' analysis, a time synchronisation of data obtained from all devices was performed, so as comparison between the several channels to be possible.

3.1 Beacons

Log files from the beacons were collected and the measure of how many room changes have been done by the participant within the duration of the protocol was performed. In some cases this number was a bit high because the participant was changing rooms while performing a walking activity (Lap 18) or during some break. However, the Lap 24 of the protocol was dedicated for controlling the beacons' performance and consisted of entering and getting out of the main room only. Results retrieved from beacons are presented in table 1.

Table 1. Beacons' derived results during the movement protocol

	Patras	Nicosia	Nancy	Sum / Weighted Average*
# of participants which performed the protocol	9	10	10	29
Room changes (mean) per participant during Lap 24	2.1	1.3	1.9	1.76
# successful room change identification (Lap 24, according to protocol)	9 (100%)	7 (70%)	9 (90%)	25 **(86.2%)**
Room changes (mean) per participant during Lap 18	*2.65*	*0.4*	*1.85*	*1.*
Other room changes (mean)	*0.8*	*0.0*	*0.15*	*0.3*

observed				
Total room changes (mean) per participant during protocol	*5.55*	*1.7*	*3.9*	*3.65*

There were some cases where the room change during Lap 24 of the protocol was not recognized, but in 86.2% of the cases the recognition was correct. The reason for not recognizing the room change might be due to some kind of lack of accuracy from the beacons or from the smart phone application.

Besides the room changes that are observed during Lap 24, there are some other room changes identified during the protocol, especially during the walking activity (Lap 18). This is due to the different layout of the premises where the protocol was applied, where one participant could have changed room while performing the 30 seconds walk activity.

In overall, the testing of beacons' required signals gives relevant results and beacons are able to identify more than 85% of room changes.

3.2 GPS

During the small-scale evaluation protocol, we requested our participants to keep a calendar of the activities they did outdoors, so that we could cross-check them with the GPS recordings saved in the FrailSafe cloud.

This request resulted in 13 activity reports (table 2), even though some accompanied by a not much detailed description. This is not very surprising because the reporting was done on a volunteer basis by the individual, and it was referring to a spontaneous activity initiated by them, without entering in the context of a strict standardised protocol. This may seem less pertinent in research means, but it better corresponds to real life circumstances.

Also, for 2 of these activity reports we are missing the GPS recordings in the FrailSafe cloud and this could have been caused either because the participants did not carry the smart phone with them, or the smart phone run out of battery while being outdoors.

Table 2. GPS recording in relation to participant's calendar notes.

Reported activity's number	Date	Calendar notes	Recording summaries
1	16/3/2018	The participant noted in the calendar that he/she was away from home for approximately 3,5 hours.	Total distance: 11.74 km Total steps: 4820 Vehicle time: 13min Walking time: 215min Walking speed: 1.34m/sec Radius covered: 2.71 km
2	17/3/2018	The participant noted in the calendar that he/she was away from home for approximately 5 hours.	Total distance: 24.1km Total steps: 2581 Vehicle time: 35min Walking time: 239min Walking speed: 1.33m/sec Radius covered: 4.47 km
3	18/3/2018	The participant noted in the calendar that he/she was away from home for approximately 4,5 hours.	Total distance: 35.4 km Total steps: 1657 Vehicle time: 48min Walking time: 155min Walking speed: 1.45m/sec Radius covered: 13.24 km
4	9/3/2018	The participant noted in the calendar that he/she was away from home for approximately 4,5 hours.	No recording found in the FrailSafe cloud
5	11/3/2018	The participant noted in the calendar that he/she was away from home for approximately 9,5 hours.	Total distance: 230 km Total steps: 5172 Vehicle time: 248min Walking time: 185 min Walking speed: 1.08 m/sec Radius covered: 83 km
6	2/3/2018	The participant noted in the calendar that he/she walked for approximately 45 minutes (4km) and was in car for another 30 minutes (5km).	Total distance: 15.15km Total steps: 6766 Vehicle time: 16min Walking time: 66min Walking speed: 1.42 m/sec Radius covered: 2.4 km
7	3/3/2018	The participant noted in the calendar that he/she walked for approximately 40 minutes (4km) and went for a visit by car for 5 hours (170km).	Total distance: 171 km Total steps: 8412 Vehicle time: 113min Walking time: 121min Walking speed: 1.17 m/sec Radius covered: 58.15 km
8	4/3/2018	The participant noted in the calendar that he/she went for a visit by car for 7,5 hours minutes (172km).	Total distance: 156.8 km Total steps: 4116 Vehicle time: 119min Walking time: 93min Walking speed: 0.91 m/sec

			Radius covered: 64 km
9	26/2/2018	The participant noted in the calendar that he/she went to pick up grandkids from school, to post office and for shopping for 5 hours (1km walking + 13km by car).	Total distance: 19.75 km Total steps: 1542 Vehicle time: 29min Walking time: 40min Walking speed: 1.44m/sec Radius covered: 5.5 km
10	27/2/2018	The participant noted in the calendar that he/she went to pick up grandkids from school, had a medical session and met friends for a total time of 7 hours (19km by car).	Total distance: 37.86 km Total steps: 2496 Vehicle time: 51min Walking time: 103min Walking speed: 1.44m/sec Radius covered: 8.74 km
11	26/2/2018	The participant noted in the calendar that he/she was out for duties for 4 hours and used car for transportation (10km).	Total distance: 12.41 km Total steps: 1231 Vehicle time: 18.3min Walking time: 49min Walking speed: 1.40m/sec Radius covered: 3.49 km
12	27/2/2018	The participant noted in the calendar that he/she was out of the house for 10 hours (about 14km combined walking and in car).	Total distance: 13.97 km Total steps: 1205 Vehicle time: 18min Walking time: 36min Walking speed: 1.36m/sec Radius covered: 7.1 km
13	28/2/2018	The participant noted in the calendar that he/she went out for coffee and had a massage session for a total time of 3 hours (11km by car).	No recording found in the FrailSafe cloud

When we summarized our recordings, we observed compliance between the outdoor activities that the participants have described and the GPS recordings.

For instance, in the report no 12 the participant has noted that he/she was out of his/her premises and estimated that the total distance he/she did (both on foot and by car) was 14km and our summary shows 13.99km. In some other cases the summaries are not that accurate, i.e. in the recording no 6, the participant estimated to have covered a total distance of 9km and we have observed 15.15km. This variation can be caused either by the uncertainty of the GPS signal (especially on areas of low coverage), or by an inaccurate calendar kept by the participant. However, these variations are probably not significant, and they capture the outdoor moving general pattern for each participant.

For others, the reported total time spent outdoors coincides well with what has been recorded by the GPS; e.g. in the report no 1 there have been about 210 minutes noted as outdoor activity, while the GPS shows 228 minutes, for report no 2 the participant noted about 300 minutes and the GPS showed 274, while for others (like recordings no 3, 5 and 7 those estimations differ slightly, probably because the GPS does not record resting time, which apparently occupies a part of the time spent outdoors.

All GPS recording referring to walking speed seem plausible, since they range between 0.9 and 1.45m/sec.

Furthermore, we evaluated our GPS measurement collection software (GPS Logger) towards another competitor application (Pacer). Our software collects a wide range of data by combining the GPS signal and the sensors of the phone. The Pacer app uses only the internal sensors of the phone and measures the walking time, distance and steps of the user. In order to validate that the GPS Logger data are consistent, we installed the Pacer app and collected recordings from both apps for 165 sessions. In the following table we present a comparison between the recordings of the two apps for the first 50 sessions.

The Spearman correlation between the measurements of the two apps is presented in table 3.

Table 3. Correlation between recordings from the GPS and a pedometer application.

Recording parameter	Spearman correlation
Steps	99.75%
Walking distance in km	53.45%
Walking time in min	41.83%

The two apps measure almost the same steps for the majority of the recordings, leading to a high correlation (99.75%). However, the walking time and distance measured by the two apps differs significantly (41.83% and 53.45% respectively). This is due to the different method used to measure these parameters. The Pacer app uses the accelerometer of the smartphone to calculate the steps that the user has performed and tries to estimate the distance covered. On the other hand, the GPS Logger does not rely on the accelerometer but uses the GPS signal to measure the walking time. The advantage of using the GPS signal is that it has a high accuracy outdoors and it is probably the best way to measure outdoor walking activities. However indoors it cannot capture easily the user’s movement and shows poor accuracy. This is the reason that in the FrailSafe project we use the GPS Logger only for the outdoor monitoring of our participants.

3.3 WWBS

3.3.1 Heart Rate

In the end of the protocol (Lap 26), the investigator used the blood pressure measuring device in order to measure the heart rate of each participant. The WWBS, which the participant was wearing during the implementation of the protocol, collected automatically, heart rate measurements, accompanied with an index showing the quality of the measurement. Low quality measurements are usually caused by wrong appliance of the WWBS, as it needs to be worn under clothes and its strap should be tight enough to have good electric contact with the skin but not extremely tight which can lead to interferences. Throughout the project the values which do not have an acceptable quality are discarded both from the analysis and the creation of the Virtual Patient Model of the participant.

Furthermore, we checked the validity of the collected measurements for the heart rate, by comparing them with the ones recorded by the nurses. Out of 29 participants, 20 of them had heart rate measurements with high quality (69%), 4 with medium quality (13.8%) and 5 with low quality (17.2%) (Table 4). The WWBS-acquired high-quality measurements across the three centres are quite close to the ones measured by the blood pressure measurement devices, as the values differ only by 2.92% (Table 5). Even medium quality measurements show an acceptable average difference between the 2 devices of less than 10%.

Table 4. Comparison between heart rate acquired by the WWBS sensor and the blood pressure measurement device.

Participant's ID	Heart frequency measured by the investigator using blood pressure measurement device	Heart frequency measured by the WWBS during Lap 26	Absolute Difference	Quality of WWBS measurement
1084	59	138	133.90%	Low
1085	67	122	82.09%	Low
1101	62	71	14.52%	Medium
1104	77	57	25.97%	Low
1112	87	131	50.57%	Low
1113	73	72	1.37%	High
1119	66	73	10.61%	Medium
1507	64	81	26.56%	Medium
1515	75	74	1.33%	High
2006	80	83	3.75%	High

2083	68	78	14.71%	High
2085	72	73	1.39%	High
2091	80	137	71.25%	Low
2094	73	78	6.85%	High
2095	81	86	6.17%	High
2099	68	71	4.41%	High
2100	55	56	1.82%	High
2102	67	70	4.48%	High
2114	76	79	3.95%	High
3095	97	99	2.06%	High
3096	90	91	1.11%	High
3104	66	67	1.52%	High
3106	62	59	4.84%	High
3107	79	79	0.00%	High
3109	77	75	2.60%	Medium
3110	66	67	1.52%	High
3119	83	84	1.20%	High
3592	82	83	1.22%	High
3593	69	73	5.80%	High

Table 5. Average difference of heart frequency measurements between the blood pressure measuring device and the WWBS sensor, according to WWBS signal quality status.

	Average
Average Difference in High Quality measurements	2.92%
Average Difference in Medium Quality measurements	9.92%
Average Difference in Low Quality measurements	72.19%

However, when the two systems failed to give comparable results it might be the case of probable arrhythmia (for instance atrial fibrillation) which would introduce measurement errors in both measurement systems.

3.3.2 Breathing rate

The WWBS is comprised of sensors for the recording of the breathing rate (br) and breathing amplitude (ba).

In protocol's lap 22, the participants were asked to take 5 breaths quickly in order to test the sensitivity of the WWBS sensors for being able to capture changes in breathing rate compared to the rest of the monitored activities. Table 6 presents the results of the relevant WWBS sensors (ba and br) during lap 22 and the other laps altogether (not lap 22).

Table 6. Results from sensors relevant to breathing during lap 22 and the rest of the laps.

sensors	lap 22	not lap 22	p-value
	mean values (standard deviation)		
ba (in millivolts)	86,31 (10,49)	101,02 (51,68)	0,38
br (in breaths per minute)	27,77 (1,43)	23,3 (5,50)	0,05

We performed a two-sample t-test on the values of breathing amplitude and breathing rate with the null hypothesis that the data come from independent random samples from normal distributions with equal means and equal but unknown variances. For both measurements ('ba' and 'br') the test did not reject the null hypothesis at the 5% significance level (for 'ba': p-value >0.05, confidence interval = [-48.53, 19.11], for 'br': p-value=0.05, confidence interval = [-0.02, 8.96]). However, this result was in the limits of statistical significance for the breathing rate sensor, possibly related to a lack of power due to the small sample size.

3.3.3 Walking activities

Two walking activities have been performed during the monitoring protocol, the Timed Get Up and Go test (lap 16) and the Gait speed test (lap 18).

Transfer-related signals from sensors of the WWBS have been compared between each of these laps and the rest of the laps not including walking activity. Results are presented in tables 7 and 8.

Table 7. Results from sensors relevant to transfer during lap 16 (the Timed Get Up and Go test) and the rest of the laps.

sensors	lap 16	not lap 16	p-value
	mean values (standard deviation)		
acc	1056 (41,09)	1062 (82,40)	0,80
gyro	9,63 (11,78)	14,72 (26,34)	0,08
gyro_torso	NaN	16,11 (27,02)	0,07
acc_torso	NaN	0,90 (0,07)	0,96
gyro_left_forearm	**8,06 (9,11)**	**20,52 (32,44)**	**0,01**
acc_left_forearm	0,68 (0,02)	0,69 (0,06)	0,97
gyro_left_shin	10,14 (15,29)	21,37 (49,05)	0,06
acc_left_shin	0,78 (0,04)	0,80 (0,14)	0,89
gyro_right_shin	12,5 (21,35)	20,65 (48,9)	0,21
acc_right_shin	0,79 (0,06)	0,80 (0,16)	0,93

gyro_right_forearm	**10,85 (12,89)**	**25,70 (40,33)**	**0,00**
acc_right_forearm	0,90 (0,03)	0,91 (0,09)	0,94

Table 8. Results from sensors relevant to transfer during lap 18 (the Gait speed test) and the rest of the laps.

sensors	lap 18	not lap 18	p-value
	mean values (standard deviation)		
acc	1058,2 (58,39)	1059,5 (80,90)	0,96
gyro	17,01 (18,67)	14,26 (25,46)	0,47
gyro_torso	22,56 (28,16)	15,39 (26,17)	0,18
acc_torso	0,91 (0,07)	0,90 (0,07)	0,95
gyro_left_forearm	20,07 (21,55)	19,03 (30,13)	0,88
acc_left_forearm	0,67 (0,04)	0,67 (0,06)	1,00
gyro_left_shin	24,98 (37,46)	20,28 (47,83)	0,51
acc_left_shin	0,79 (0,10)	0,78 (0,14)	0,99
gyro_right_shin	26,38 (39,56)	19,62 (47,67)	0,38
acc_right_shin	0,79 (0,13)	0,79 (0,15)	0,95
gyro_right_forearm	28,82 (33,83)	24,64 (39,19)	0,47
acc_right_forearm	0,90 (0,08)	0,90 (0,09)	0,99

We performed a two-sample t-test on the values of the accelerometer ('acc') and the gyroscope (‘gyro’) with the null hypothesis that the data come from independent random samples from normal distributions with equal means and equal but unknown variances. For both measurements ('acc' and 'gyroscope') the test did not reject the null hypothesis at the 5% significance level except for the gyroscope measurements from the right and left forearm in the lap 16 in comparison to the other laps (for ‘gyro_left_forearm’: p-value =0.01 and for ‘gyro_right_forearm’: p-value<0.001).

3.3.4 Activities’ classification

The collected recordings from the WWBS were given as input to the physical activities’ classification algorithm developed for WP4 (D4.2). The algorithm automatically classified the recordings in one of the following categories:

- Sitting/standing: state indicating low movement of the participant.
- Walking: state indicating walking activity.
- Stairs: state indicating walking up/down the stairs.
- Transition: transition between certain states, e.g. rising up from chair etc.

Then we cross-checked the annotations described in the protocol for each Lap, in order to calculate the accuracy of our classification algorithm. We made the following assumptions:

- During Laps 16, 18 and 24, participants are walking throughout the recording, without stopping.
- During Laps 3, 5, 7, 8, 10, 11, 13, 14 and 22, participants are either sitting or standing without doing sudden movements that could be classified as walking or transition.
- During Laps 1 and 20, participants perform sudden movements (such as getting up from a chair) without resting before or after the movement.

In table 9 the accuracy of the activity classification algorithm based on the assumptions made above is listed, as estimated by the comparison of the physical activities' classification algorithm developed for WP4 and the description of the activity of each lap.

Table 9. Accuracy or activity classification algorithm.

	Accuracy (percentage of activities correctly recognised)
Walking accuracy	0.61
Standing/sitting accuracy	0.34
Transition accuracy	0.68
Stairs accuracy	*(not applicable)*
Overall accuracy	0.54

The accuracy for standing/sitting activities appears low, but it is justified as during the Laps of the protocol the participant could perform some sudden movements even though he/she is expected to stand still. As an example, during Lap 3, the participant is not expected to move significantly but a sudden movement could misclassify his activity into a transition. Also, while standing on one leg (Laps 7 and 8) and on two legs (Laps 10, 11, 13, 14), the participant could lose balance momentarily and move significantly, thus affecting the observed accuracy. Under this perspective, this deviation between the actual signal received and the trained algorithm of "standing-still" could be due to a loss of balance or a compensatory movement to this out-of-balance situation, and thus could actually imply a physical frailty index rather than an inner weakness of the measuring system.

On the other hand, our algorithm can classify well the walking activities which are considered important for monitoring older people.

Similarly, the accuracy of transition states is very satisfying.

Since the algorithms were trained in older people as well, it could be that a greater variation is presented between them in regards of standing/sitting physical activities than in regards of walking or transition movements.

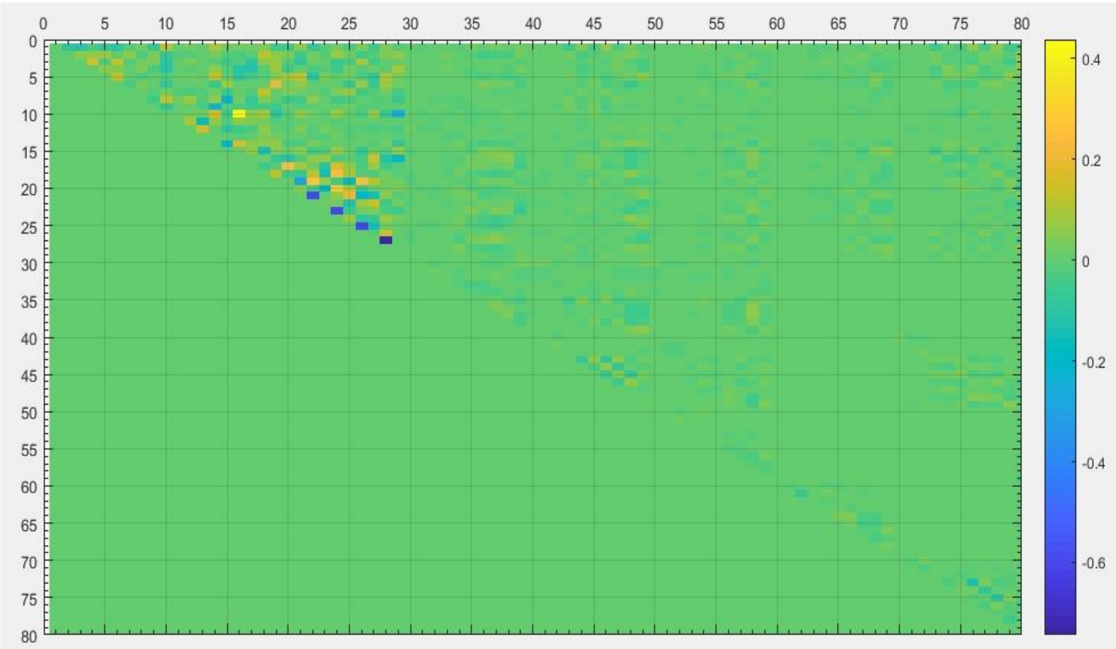
3.3.5 Redundancy of sensors

In order to study the necessity of using all sensors (the standard ones used in Frailsafe and the additional ones examined in this small-scale evaluation study) we calculated the correlation between each pair of sensors. The correlation is shown in color scale (yellow for positive values and blue for negative values) for each subject in Figures 3 to 26 of annex 3. The order of sensors is presented in Annex 1.

The coordinates of each colored dot indicate the pair of sensors, for example the dot at (3,4) shows the correlation between 'br' and 'ecg_hr'. Only the upper triangular matrix is shown since the lower part is symmetric.

It can be observed that some pairs of sensors are highly correlated, positively as well as negatively. In order to examine whether the same pair of sensors are correlated across all subjects, we calculated the average pairwise correlation and illustrate it in Figure 27.

Figure 27: Pairwise correlation of means of sensors' measurements



The correlation values have dropped significantly which means that different sensors pair up for each subject.

Only 4 pairs seem to have moderate to high correlation for all participants, as shown next:

R('qel0', 'qel1') = -0.61
R('qel2', 'qel3') = -0.60
R('qer0', 'qer1') = -0.61
R('qer2', 'qer3') = -0.74

Qe is an abbreviation for 'quartenion' which is a compact output signal that is provided instead of delivering 9 values (acc_x, acc_z, acc_y, mag_x, mag_z, mag_y, gyro_x, gyro_z, gyro_y), where l refers to left arm and r to the right one. The highest correlation (-0.74) is observed between the quartenions of the right arm located in positions 2 and 3.

These findings highlight the correctness of the decision of putting IMUs on the arms in the latest version of the WWBS.

4 Annexes

Annex 1

order	sensor
1	'resp_piezo'
2	'ba'
3	'br'
4	'ecg_hr'
5	'ecg_rr'
6	'ecg_hrv'
7	'ecg_quality'
8	'acc_x'
9	'acc_y'
10	'acc_z'
11	'gyro_x'
12	'gyro_y'
13	'gyro_z'
14	'mag_x'
15	'mag_y'
16	'mag_z'
17	'q0'
18	'q1'
19	'q2'

20	'q3'
21	'qel0'
22	'qel1'
23	'qel2'
24	'qel3'
25	'qer0'
26	'qer1'
27	'qer2'
28	'qer3'
29	'act_predicted'
30	'gyro_x_torso'
31	'gyro_y_torso'
32	'gyro_z_torso'
33	'acc_x_torso'
34	'acc_y_torso'
35	'acc_z_torso'
36	'mag_x_torso'
37	'mag_y_torso'
38	'mag_z_torso'
39	'bar_torso'
40	'gyro_x_left_forearm'
41	'gyro_y_left_forearm'
42	'gyro_z_left_forearm'
43	'acc_x_left_forearm'
44	'acc_y_left_forearm'
45	'acc_z_left_forearm'
46	'mag_x_left_forearm'
47	'mag_y_left_forearm'
48	'mag_z_left_forearm'
49	'bar_left_forearm'
50	'gyro_x_left_shin'
51	'gyro_y_left_shin'
52	'gyro_z_left_shin'
53	'acc_x_left_shin'
54	'acc_y_left_shin'
55	'acc_z_left_shin'
56	'mag_x_left_shin'
57	'mag_y_left_shin'
58	'mag_z_left_shin'
59	'bar_left_shin'
60	'gyro_x_right_shin'
61	'gyro_y_right_shin'
62	'gyro_z_right_shin'

63	'acc_x_right_shin'
64	'acc_y_right_shin'
65	'acc_z_right_shin'
66	'mag_x_right_shin'
67	'mag_y_right_shin'
68	'mag_z_right_shin'
69	'bar_right_shin'
70	'gyro_x_right_forearm'
71	'gyro_y_right_forearm'
72	'gyro_z_right_forearm'
73	'acc_x_right_forearm'
74	'acc_y_right_forearm'
75	'acc_z_right_forearm'
76	'mag_x_right_forearm'
77	'mag_y_right_forearm'
78	'mag_z_right_forearm'
79	'bar_right_forearm'
80	'act_real'

Annex 2

participant	total_steps	pacer_steps	total_walk_distance	pacer_distance	total_walk_time	pacer_time
1	1048	1046	0,173	0,68	11,3	8
2	1962	1980	0,144	1,3	7,5	15
3	1354	1354	1,498	0,89	111,2	10
4	6595	6577	10,380	4,34	128,8	40
5	1	9	0,000	0	0,0	0
6	3503	3535	9,567	2,33	105,1	26
7	10439	10435	14,300	6,88	220,1	75
8	13707	13705	8,315	9,04	103,1	87
9	11810	11819	11,151	7,8	175,1	87
10	3363	3361	2,921	2,21	33,9	25
11	5624	5616	6,347	3,7	99,0	39
12	491	492	3,786	0,32	160,5	3
13	5809	5816	5,148	3,8	64,3	39
14	11540	11543	9,610	7,6	123,0	80
15	12118	12206	12,886	8	166,3	83
16	12371	12287	9,977	8,1	126,9	86
17	12516	12519	12,440	8,2	170,4	88
18	40	30	0,000	0	0,0	0
19	5585	5585	6,335	3,6	83,4	38
20	4135	4143	2,889	2,73	42,7	24

21	11991	12015	8,832	7,92	114,1	71
22	6436	6438	4,424	4,24	64,9	35
23	6429	6492	4,537	4,28	78,3	41
24	11021	10955	10,125	7,23	163,8	67
25	7638	7614	5,809	5,02	77,8	45
26	2100	2107	2,245	1,3	40,8	15
27	1743	1745	8,302	1,1	184,5	12
28	1940	1938	1,032	1,2	11,0	14
29	1488	1569	0,031	1	2,3	12
30	1367	1422	0,174	0,9	13,9	10
31	1669	1533	0,409	1	18,9	12
32	1193	1194	0,056	0,7	2,6	8
33	4160	4698	14,912	3,09	158,0	26
34	14800	14303	31,414	9,43	444,7	70
35	12115	12252	21,889	8,08	299,5	57
36	4083	4157	10,523	2,74	146,1	26
37	8542	8364	12,657	5,51	207,5	49
38	2636	2569	19,935	1,69	269,2	17
39	58	90	0,365	0,05	16,2	0
40	1854	1832	1,767	1,2	25,7	12
41	266	264	0,699	0,17	30,8	2
42	1576	1575	11,349	1,03	155,9	11
43	3361	3377	8,416	2,22	104,8	22
44	4361	4385	22,092	2,8	204,8	31
45	3465	3510	10,845	2,3	122,9	26
46	5207	5160	29,527	3,4	266,4	36
47	4099	4120	9,170	2,7	142,6	29
48	4447	4437	23,618	2,9	247,5	31
49	3994	4111	21,491	27	211,1	29
50	3176	3183	8,685	2,09	86,3	21
51	7184	7228	16,006	4,76	172,9	44
52	5409	5452	11,778	3,59	141,3	37
53	4011	3987	8,283	2,63	101,0	27
54	7494	7452	13,159	4,91	170,3	47
55	1317	1327	0,254	0,8	13,7	9
56	2579	2576	1,439	1,7	44,2	19
57	1880	1880	0,235	1,2	15,9	13
58	6989	6993	9,635	4,6	139,3	48
59	3515	3516	7,760	2,3	153,0	24
60	2385	2380	2,570	1,5	42,9	16
61	7	9	0,077	0	3,5	0
62	3836	3843	12,321	2,5	238,8	24
63	4140	4141	7,091	2,7	144,7	26
64	4509	4511	9,009	2,9	249,0	29
65	4467	4498	20,926	2,9	524,1	31
66	1622	1598	0,519	1	21,8	12

67	1894	1884	3,911	1,2	119,3	14
68	11	20	0,205	0	9,5	0
69	1963	1976	2,729	1,3	39,7	14
70	5773	5775	7,836	3,81	105,4	42
71	3894	3886	8,716	2,56	121,5	28
72	7043	7043	5,652	4,64	83,6	49
73	3043	3047	2,825	2,01	54,4	21
74	1043	1050	0,118	0,69	6,4	7
75	18	17		0,01	0,0	0
76	2252	2275	3,001	1,5	39,6	20
77	1578	1573	0,934	1,03	31,4	14
78	1728	1755	1,386	1,15	30,9	15
79	2942	2915	4,408	1,92	98,1	26
80	2326	2333	1,500	1,53	20,8	21
81	1674	1670	0,066	1,1	4,2	13
82	50	57	18,801	0,03	472,8	0
83	119	121	28,152	0,07	616,7	0
84	62	75	49,644	0,04	764,4	0
85	182	179	24,571	0,11	440,7	1
86	52	49	2,309	0,03	42,6	0
87	16	6	1,075	0	19,5	0
88	0	0	0,266	0	6,2	0
89	490	512	2,325	0,33	59,8	3
90	891	889	0,918	0,58	30,7	6
91	6409	6419	9,365	4,23	108,8	44
92	1448	1451	0,267	0,95	6,6	10
93	7779	7791	15,906	5,14	207,7	58
94	1124	1097	0,550	0,72	28,5	8
95	964	988	1,345	0,65	30,3	7
96	897	919	1,578	0,6	159,7	6
97	6437	6422	31,567	4,23	388,1	37
98	3663	3665	5,411	2,41	84,3	26
99	1431	1681	14,948	1,1	111,7	11
100	3549	3825	21,546	2,52	221,8	24
101	3604	3547	35,225	2,34	441,6	15
102	2181	2269	4,759	1,49	117,6	12
103	1200	1309	0,429	0,86	9,5	6
104	4739	4713	3,319	3,1	55,7	22
105	2149	1985	18,161	1,3	197,7	12
106	3022	3548	13,109	2,3	121,4	24
107	3247	3008	11,642	2	109,1	22
108	968	1111	0,025	0,7	1,7	7
109	986	533		0,3	0,0	3
110	5781	5788	21,946	3,8	316,0	34
111	1641	1662	23,670	1	475,6	10
112	1749	1728	12,048	1,1	310,5	11

113	2101	2101	10,964	1,3	227,5	14
114	745	747	9,548	0,4	313,7	5
115	16	21	9,798	0	401,6	0
116	484	477	14,207	0,3	376,5	0,3
117	10778	10799	40,486	7,12	567,1	53
118	17027	17138	29,422	11,31	424,7	99
119	18212	18285	11,562	12,06	162,2	95
120	11947	11830	22,869	7,8	313,2	62
121	14062	14040	48,713	9,26	621,1	73
122	13548	13678	19,683	9,02	289,5	69
123	987	0	13,244	0	86,5	0
124	4408	4435	29,246	2,92	414,0	21
125	2081	2068	51,889	1,36	375,8	14
126	2150	2171	41,400	1,43	335,8	15
127	5343	5805	19,025	3,83	236,6	31
128	5187	5194	14,061	3,42	183,4	47
129	10702	10755	29,715	7,09	392,3	97
130	10584	10531	50,851	6,94	543,8	95
131	11605	11675	13,333	7,7	167,9	106
132	2151	2089	7,845	1,37	148,4	18
133	4323	4343	7,338	2,86	95,8	39
134	8116	8090	13,224	5,33	130,1	73
135	5952	5949	25,436	3,9	595,5	39
136	6851	6858	61,609	4,5	798,3	42
137	3575	3568	17,786	2,3	519,7	24
138	0	0	16,841	0	430,2	0
139	7	0	7,487	0	194,0	0
140	124	578	0,061	0,38	9,7	5
141	11246	11065	14,315	7,3	196,8	100
142	11603	11709	11,485	7,72	147,0	106
143	12045	11757	49,659	7,75	661,9	106
144	15821	15825	23,796	10,44	325,4	143
145	8133	8366	18,046	5,52	235,1	76
146	3377	3092	20,921	2	178,9	21
147	4256	4354	28,686	2,8	366,0	27
148	5635	5395	29,872	3,5	367,6	33
149	16365	16974	28,197	11,2	398,8	107
150	2804	2336	4,353	1,5	176,6	15
151	112	0		0	0,0	0
152	156	521	0,000	0,3	0,0	4
153	6618	6272	10,780	4,1	125,0	43
154	7905	7896	12,980	5,2	145,0	52
155	2110	2146	29,875	1,4	223,9	15
156	3943	3915	8,668	2,5	83,7	26
157	2630	2619	12,257	1,7	129,7	18
158	2440	2447	1,478	1,6	37,2	18

159	4694	4700	3,738	3,1	50,0	34
160	3660	3660	8,215	2,4	126,7	27
161	2258	2330	24,653	1,5	396,5	17
162	3666	3590	1,284	2,3	57,7	27
163	468	661	0,040	0,4	3,1	4
164	598	734	2,273	0,48	134,4	5
165	4100	4109	22,931	2,71	236,8	25

Annex 3.

Figure 3

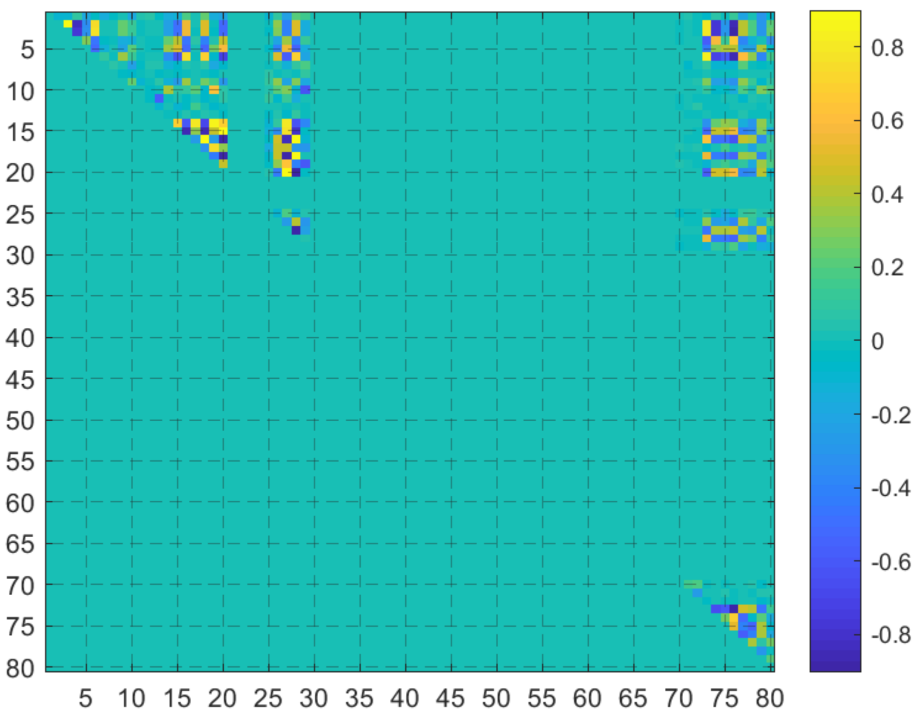


Figure 4

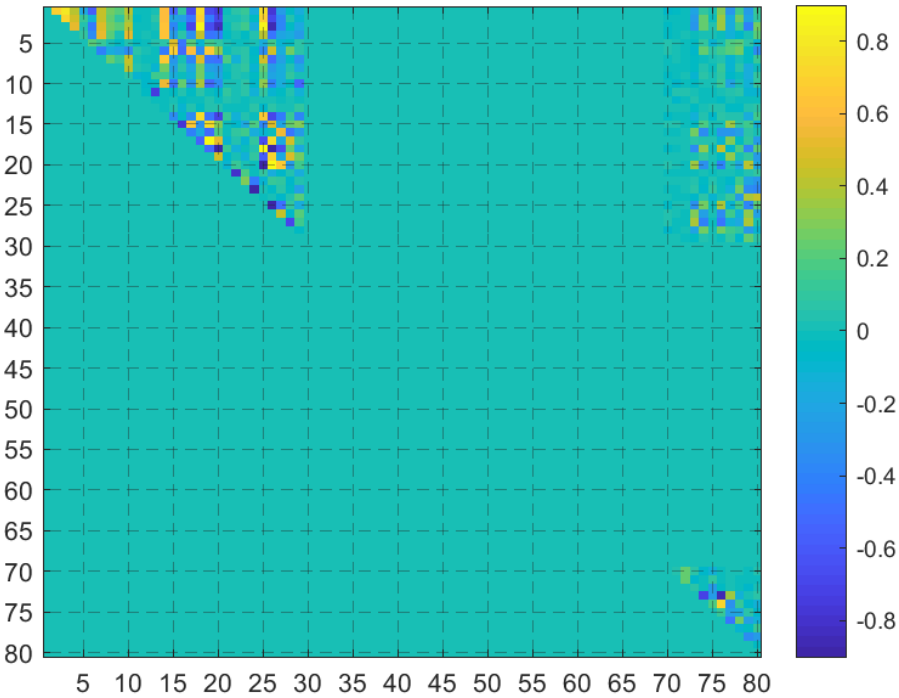


Figure 5

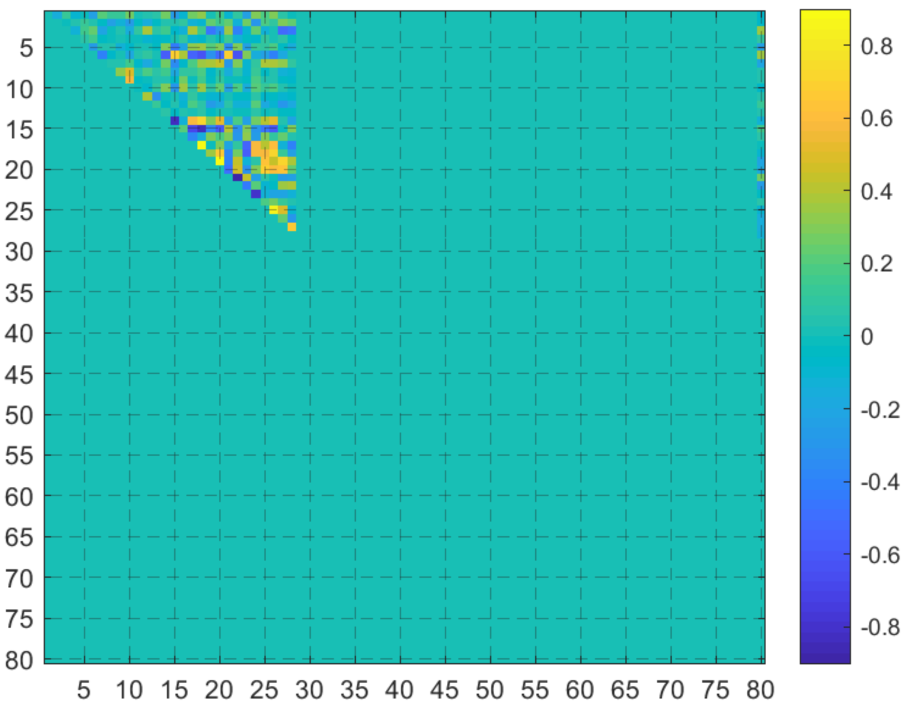


Figure 6

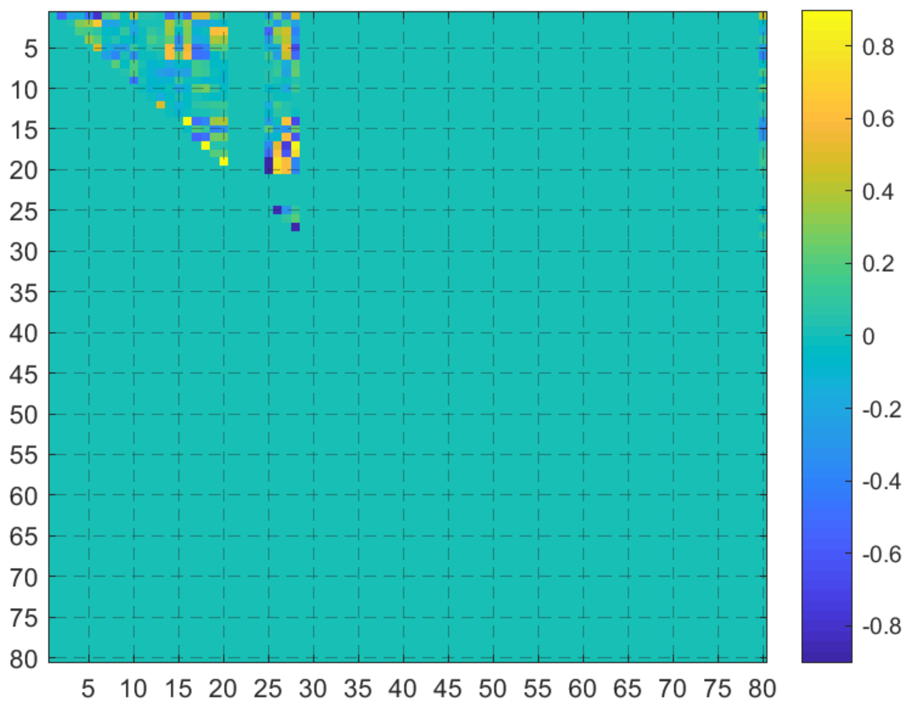


Figure 7

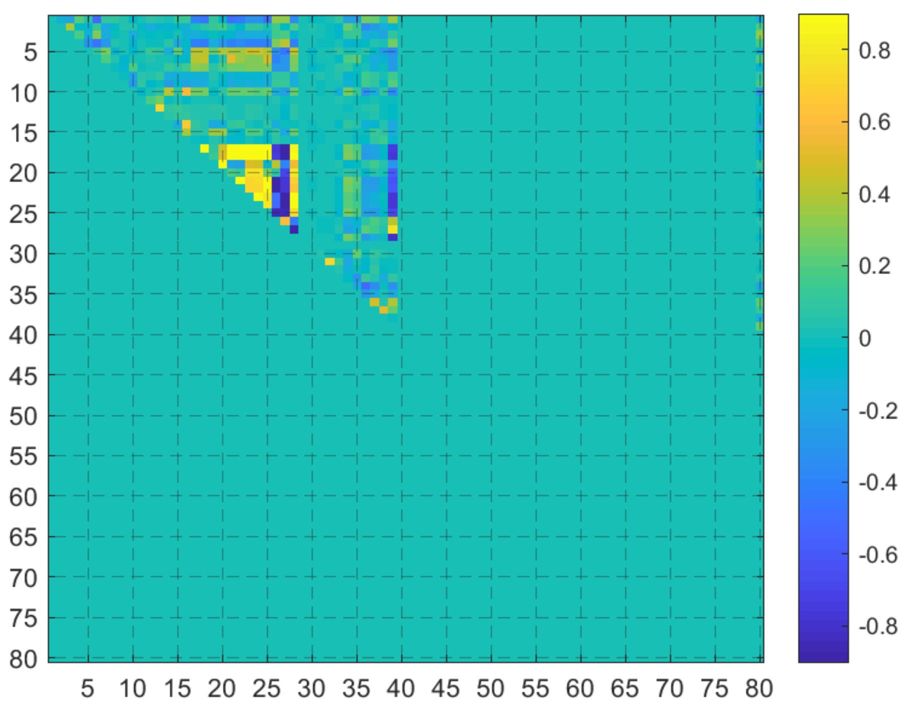


Figure 8

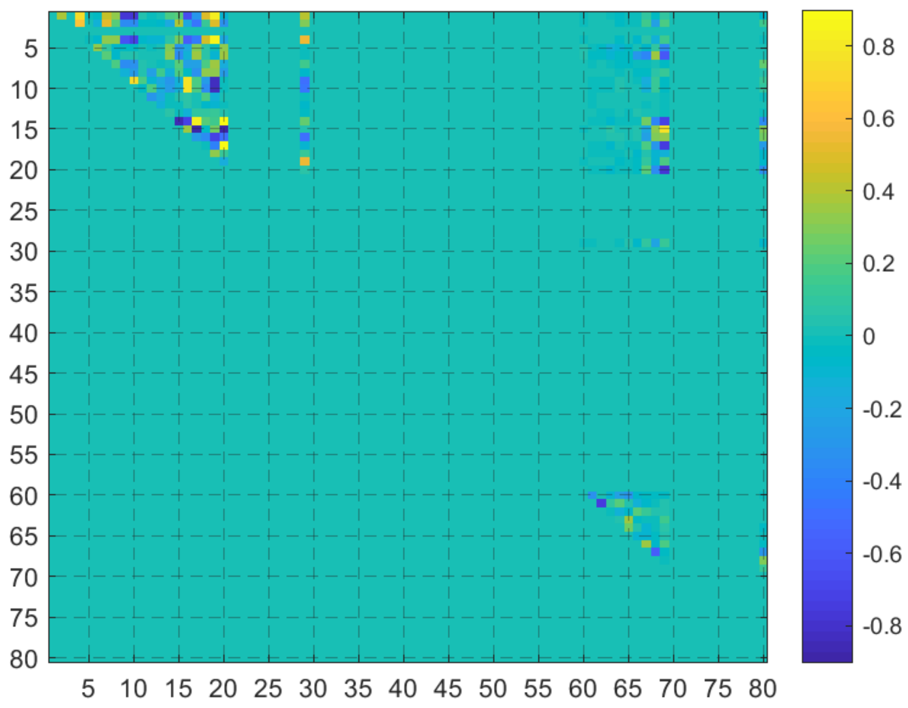


Figure 9

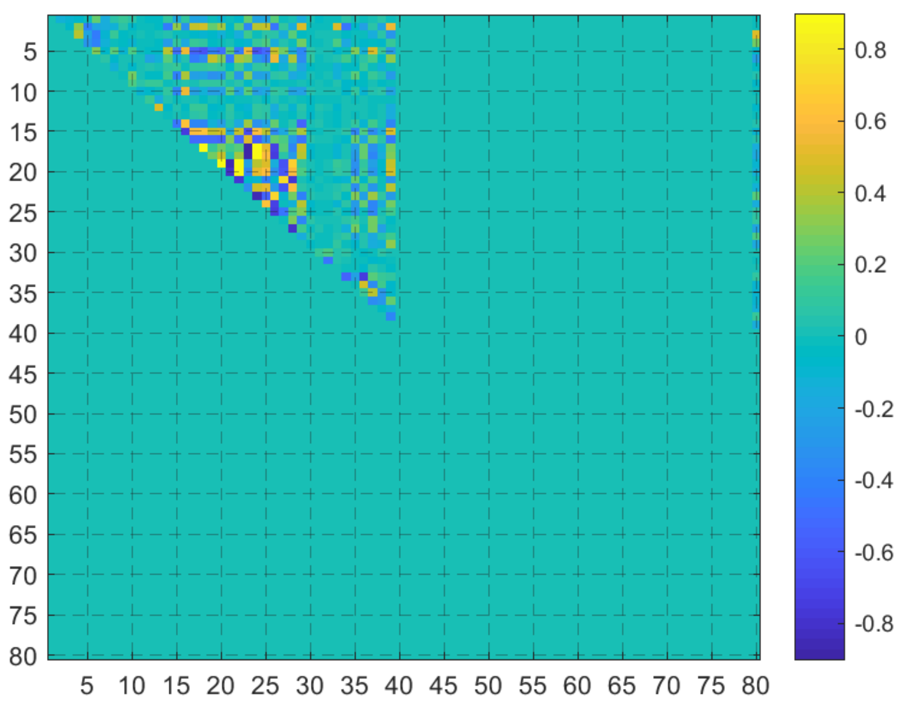


Figure 10

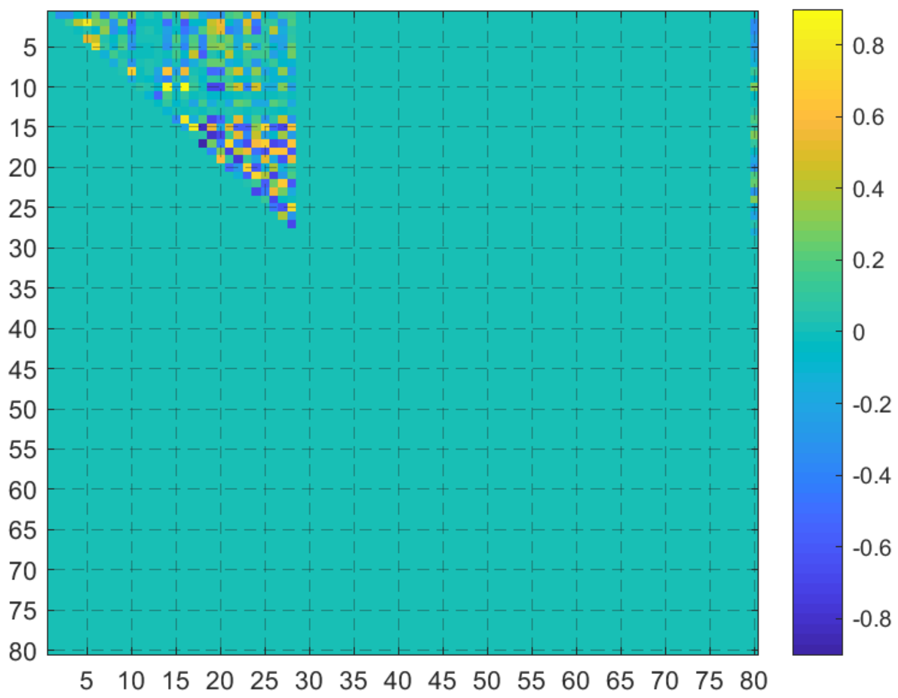


Figure 11

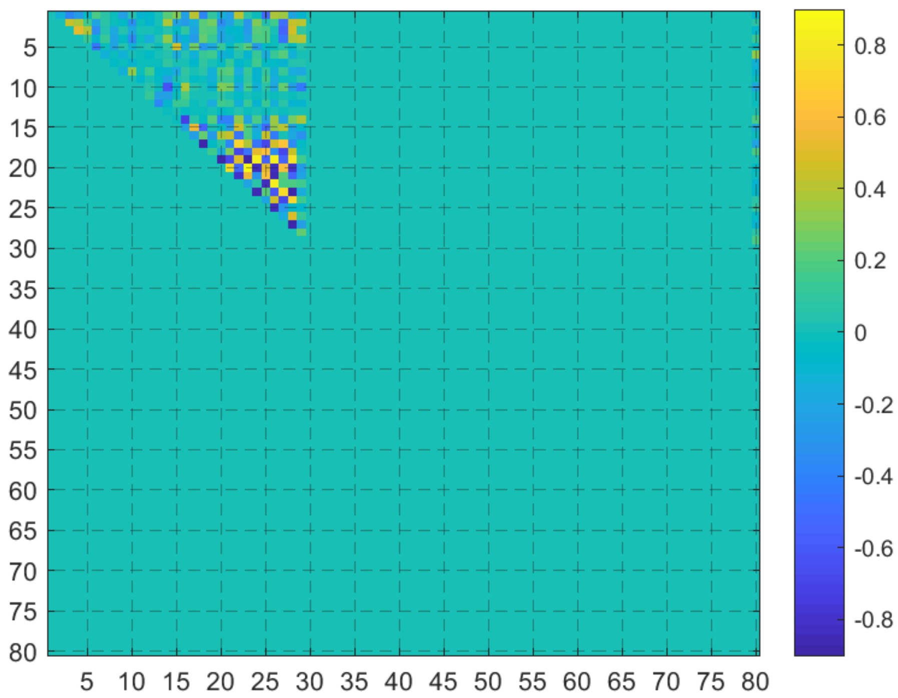


Figure 12

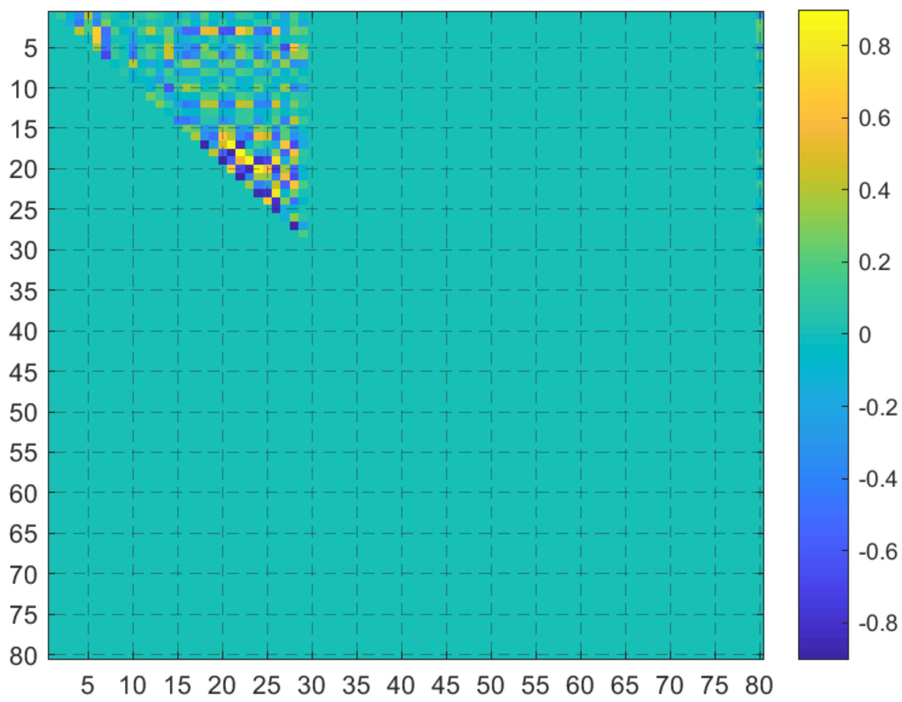


Figure 13

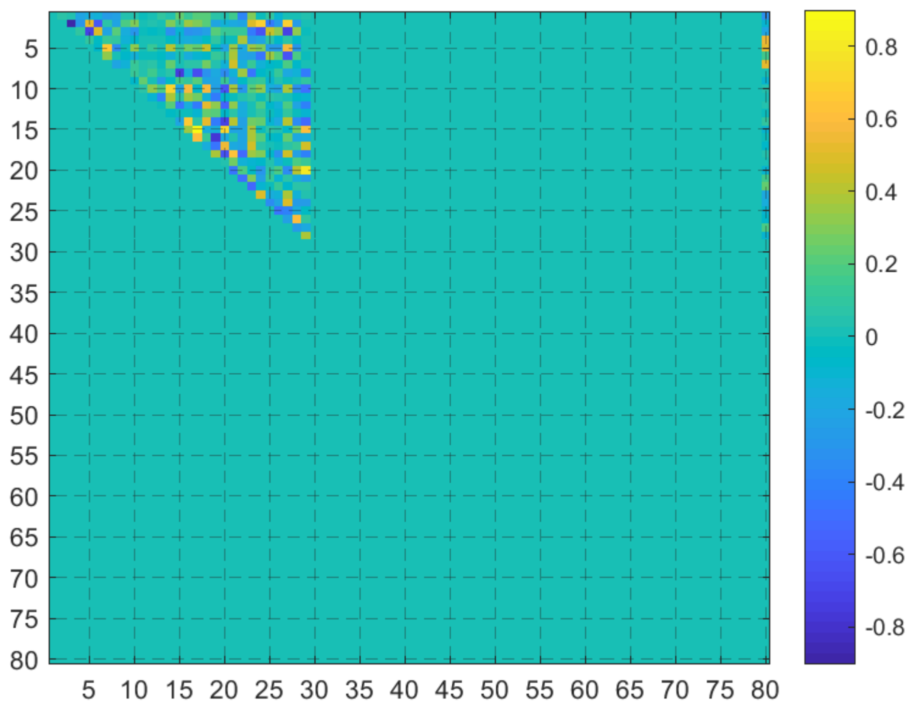


Figure 14

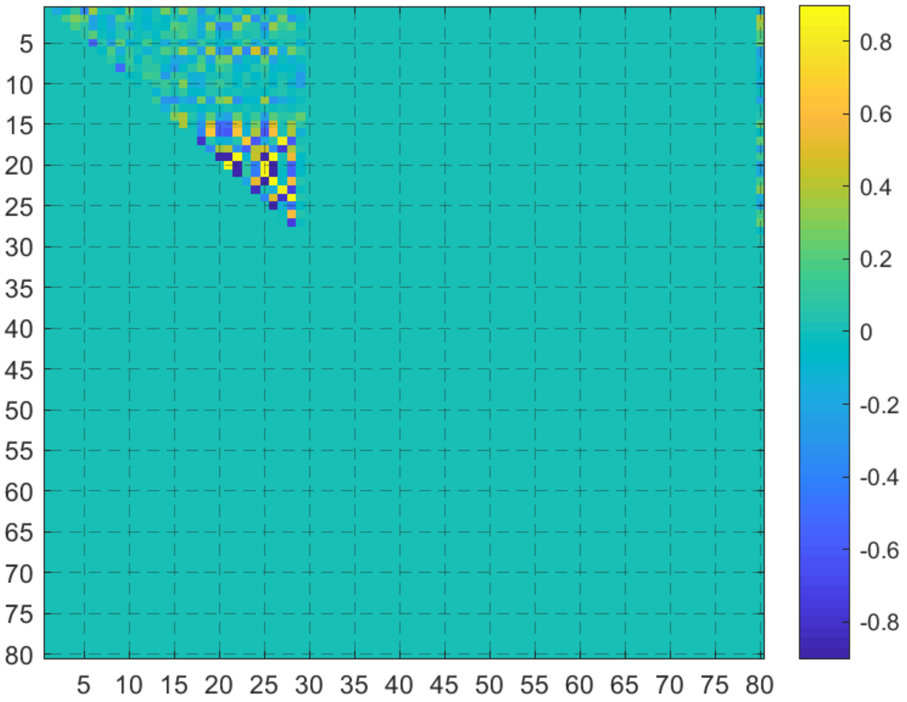


Figure 15

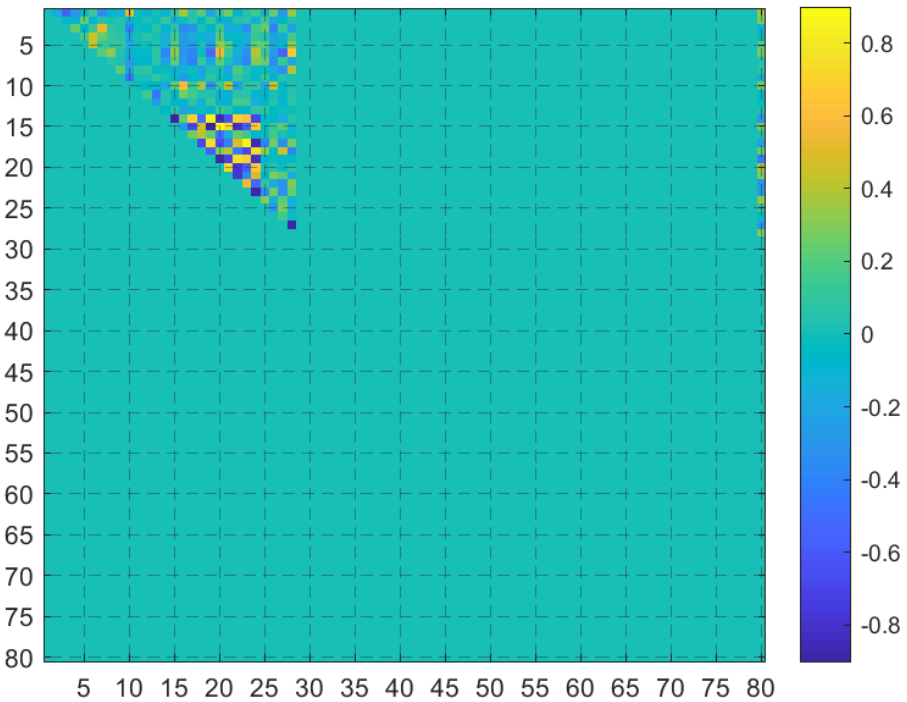


Figure 16

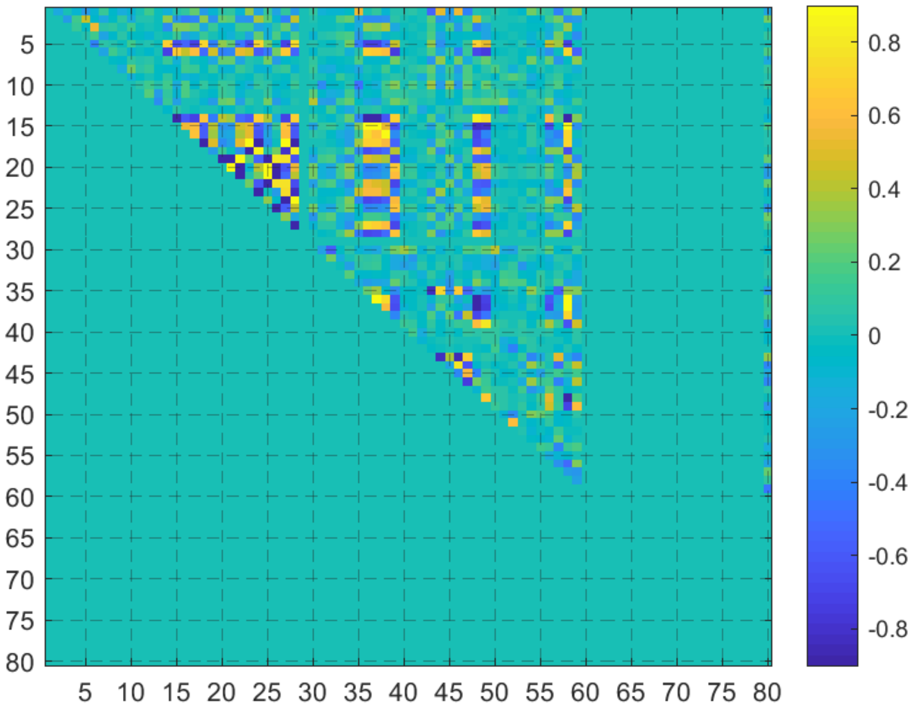


Figure 17

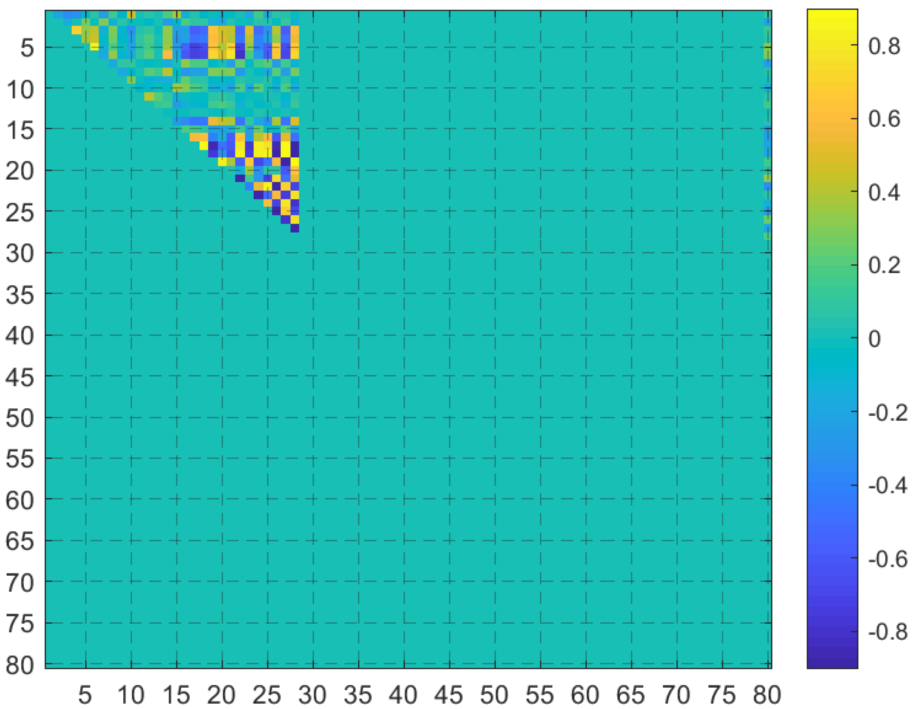


Figure 18

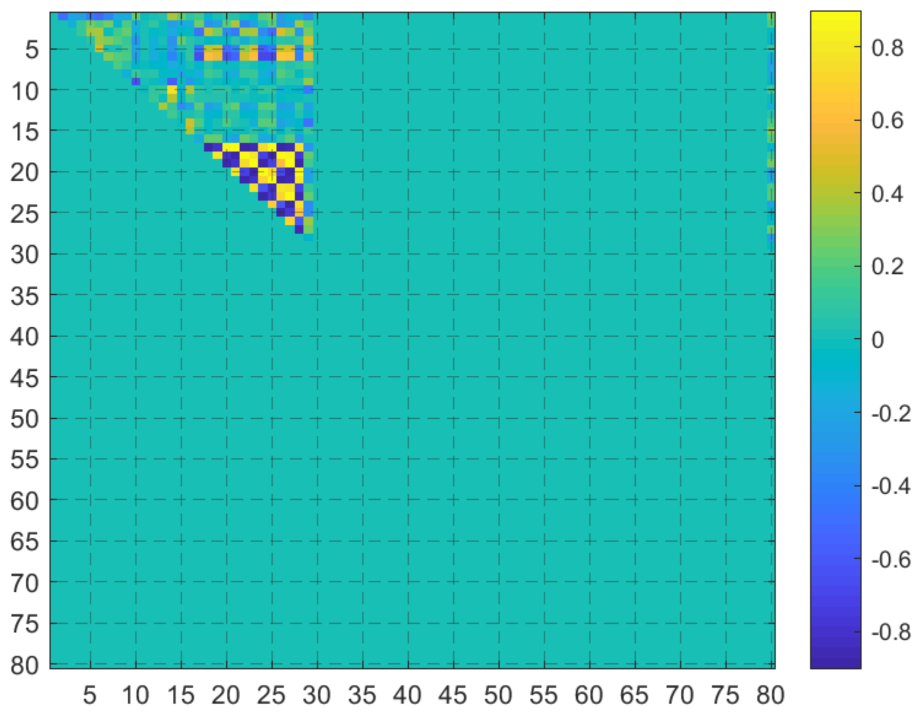


Figure 19

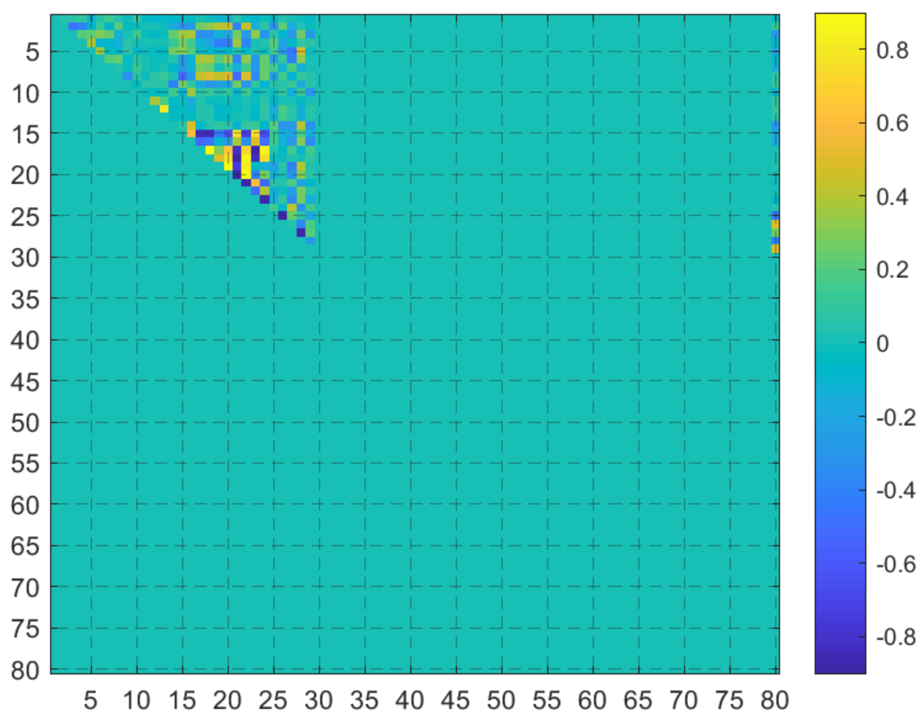


Figure 20

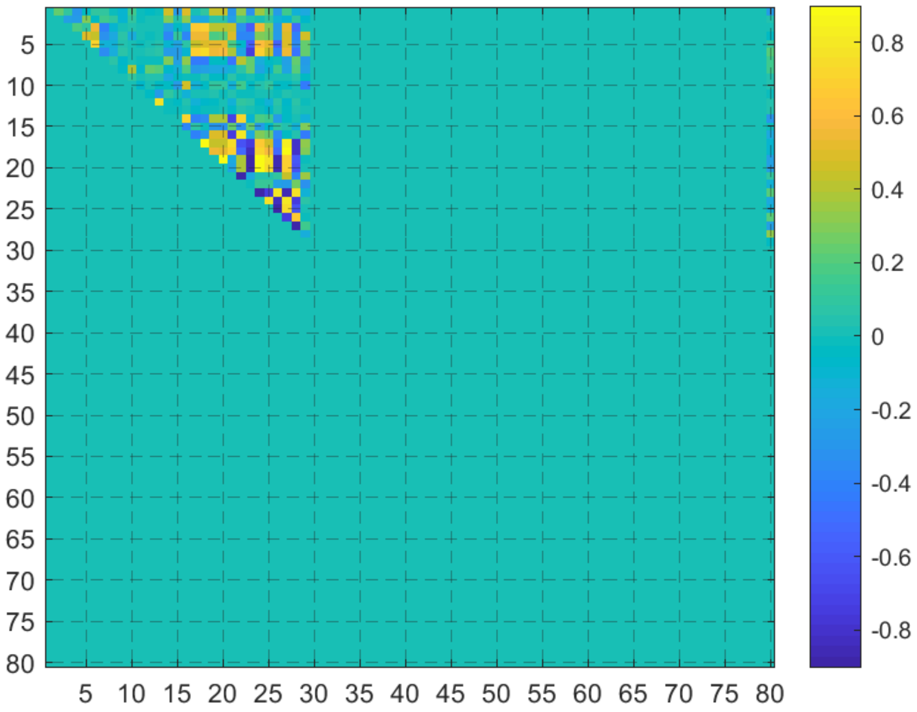


Figure 21

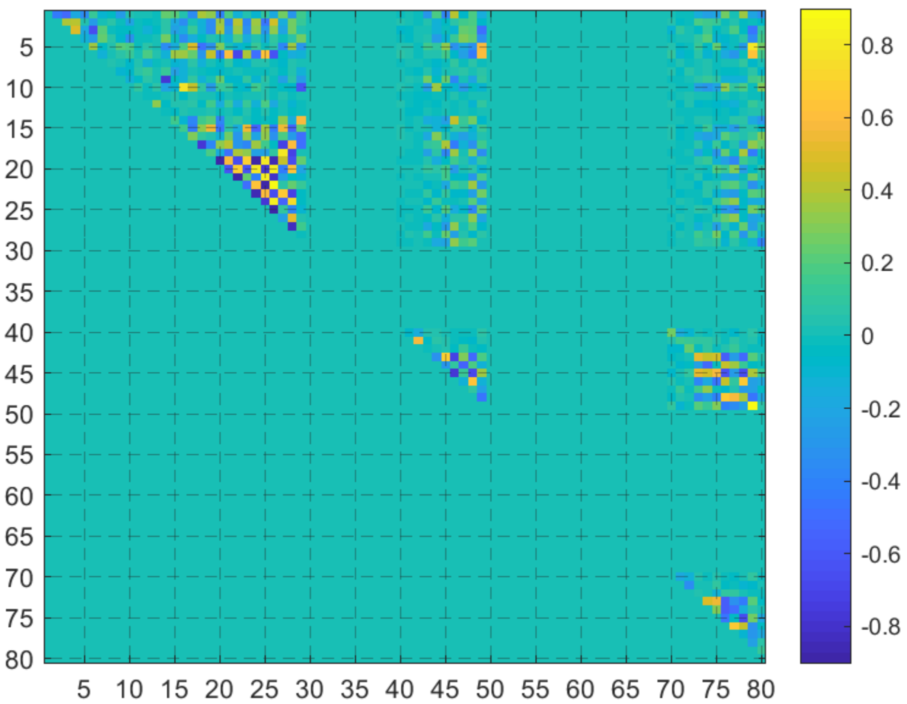


Figure 22

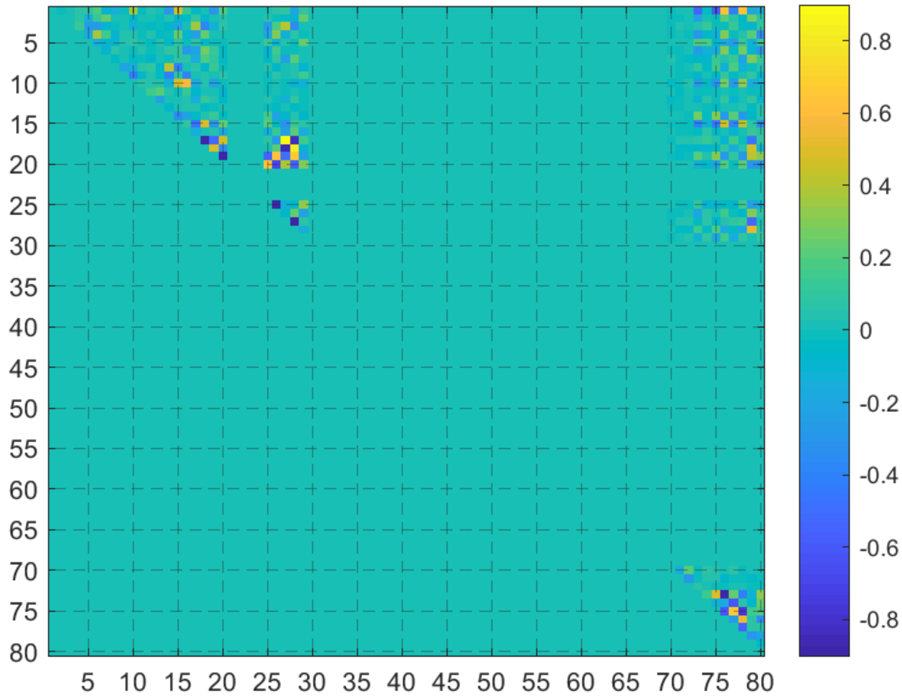


Figure 23

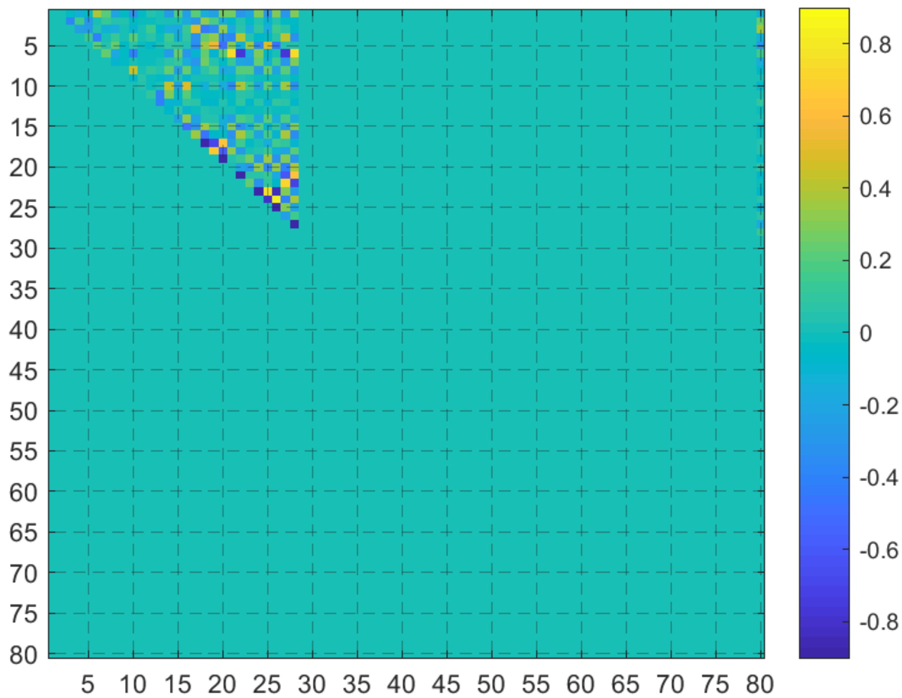


Figure 24

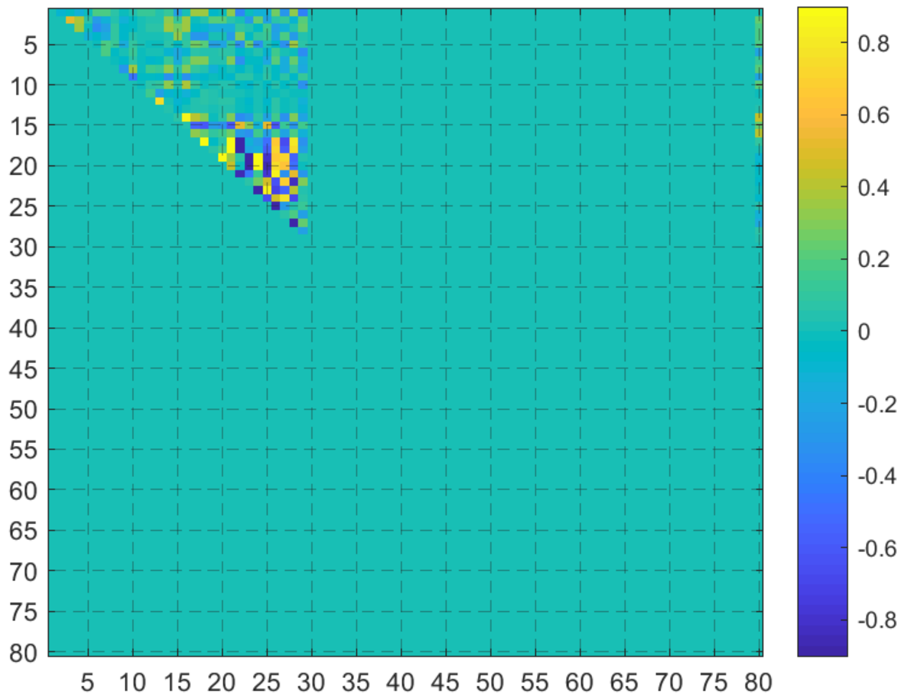


Figure 25

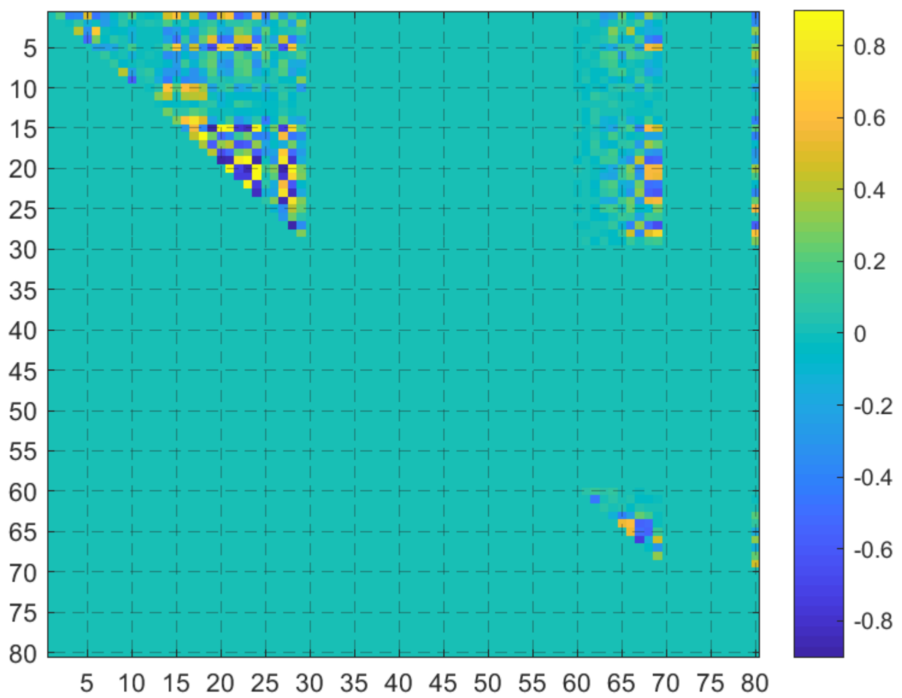
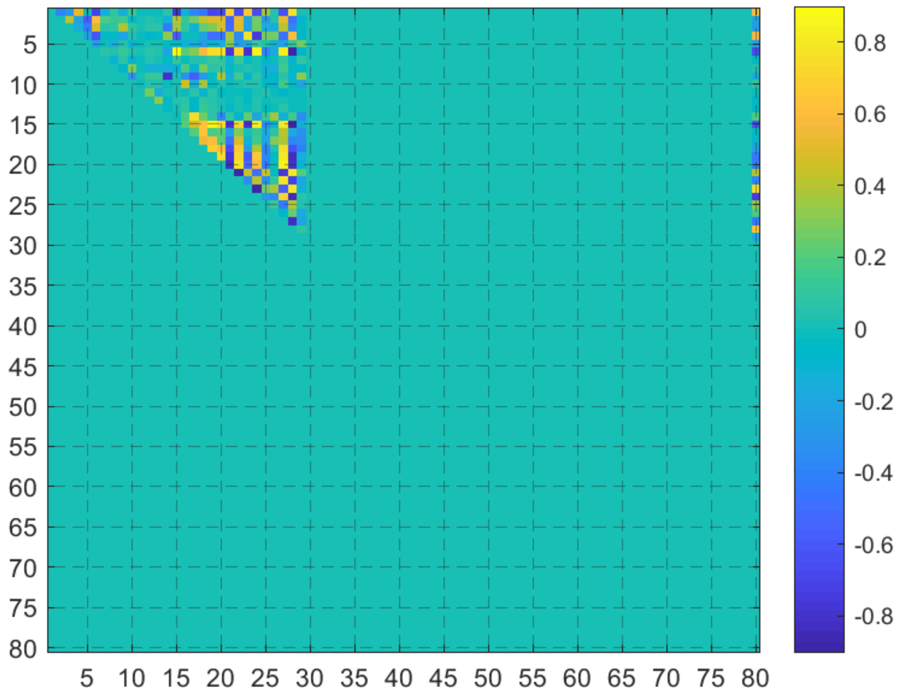


Figure 26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80
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8