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Acronyms and Abbreviation

CDI	Crowd Dynamics International Limited
EC	European Commission
EMT	Executive Management team
FZJ	Forschungszentrum Julich Gmbh
GA	Grant Agreement
INRIA	Institut National De Recherche En Informatique Et Automatique
KPIs	Key Performance Indicators
ONH	Onhys
PO	Project Officer
UL	University of Leeds
ULM	Universität ULM
URJC	Universidad Rey Juan Carlos
WP	Work-package

1. Introduction

This deliverable describes the efforts made in task T1.2 "Laboratory experiments on small groups". The goal of this task is to conduct experiments under controlled laboratory conditions with individual participants or small groups that help to fulfill the objectives of WP1.

In crowds, people are often being pushed from different directions and in situations when people are faced with strong external perturbations, they need to adjust their postures immediately to reduce the risk of falling. If one falls in the chaos of the crowd, there is a high risk of injury and even possible fatal outcomes. Therefore, to avoid falling one needs to have a well-developed skill to maintain balance via postural control which effectively ensures that the body's center of mass remains within its base of support. This can be done by using different postural strategies following (reactive postural control) or even preceding (anticipatory postural control) such perturbations.

Therefore, our focus is to observe and measure postural control in balance-perturbing situations. Specifically, we are using external perturbations such as a push at the back of the participants to elicit both anticipatory and reactive postural control responses. By repeating these perturbations in 10 to 30 consecutive trials we challenge the participant's neural control of movement and expect to elicit a learning effect. That is, we expect the participants to gradually learn how to react faster and appropriate to such perturbations in order to maintain their balance.

We intend to apply such perturbations either manually (i.e., pushing with a hand by the examiner or another participant) or by using a newly designed and built mechanical perturbation device which allows more control over the pushing force. The perturbation device would be especially useful in the experiments where we plan to induce a series of consecutive perturbations with the same push profile (velocity and magnitude of the applied force). In any case of either manual or mechanical perturbation, the magnitude of the pushing force never presents any health hazard to the participants. Namely, the intent of these perturbations is to manipulate balance of the participants in a way that in case of a loss of balance, the participants will be able to regain their balance by simply changing their posture (bending in knees or/and hips) or in most extreme cases making a step.

2. Experiments conducted

At the time of publication of this report, all experiments were performed as planned. We are confident that these data serve their purpose within the project. In the following, experiments that belong to task T1.2 "Laboratory Experiments on small groups" are described.

2.1. Manual push of individual (ULM)

2.1.1. Objective

Perturbation based postural control training has been proved to be an effective method to improve the speed of reactive responses and reduce the accident rate of falling. With this study we aimed to elicit the learning effect of perturbation training and investigate how learning changes under different intensities of pushing force.

2.1.2. Methods and types of data

We measured postural reactions of two participants in a pushing/falling (losing balance) situations (see Figure 1). Participants were standing one in front of another and the participant standing at the back (the pusher) pushed the participant in the front (a faller) at shoulder blade level, so that the front participant needed to either adjust their posture (bend in the hips, lean forward...) or make a step to remain in balance and prevent a fall.

Sixteen healthy students (10 females, 6 males) from ULM University participated in this study as volunteers and had given their written consent to the data usage. The experiment was conducted from February to May of 2022 at the Applied Cognitive Psychology laboratory of ULM University.

We collected the data of ground reaction forces, the pushing force and muscle activations. Ground reaction forces data with a sampling rate of 1000 samples/s were collected by two force plates (9260AA, Kistler Instrumente AG, Winterthur, Switzerland) placed under the feet of both participants. The pushing force that the pusher applied onto the faller was measured with a 1-axis load cell (KM38, ME-Messsysteme GmbH, Germany) mounted on one of the palms of the pusher with a sampling rate of 250 samples/s. The EMG electrodes were placed on the dominant leg (SOL, Soleus and GM, Gastrocnemius medialis) muscles of both participants. The myoelectric activity of those muscles was measured by using the Delsys Trigno Research+ System with a sampling rate of 2000 samples/s.

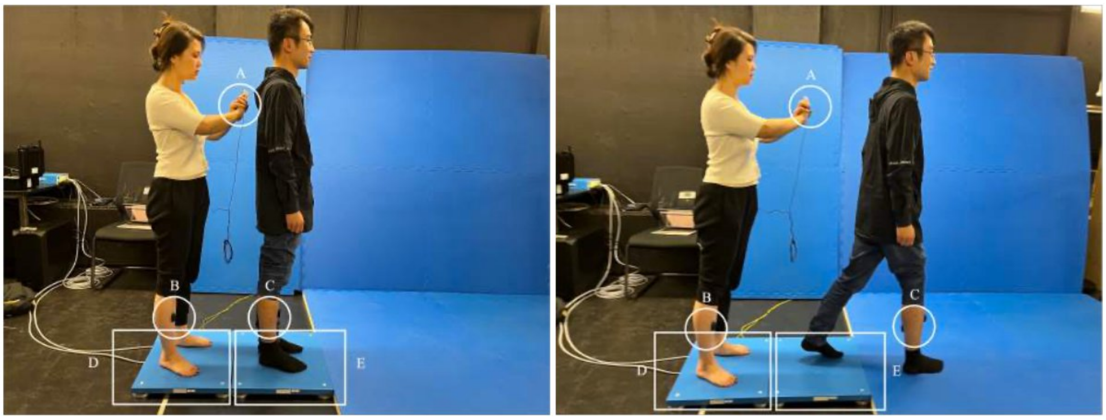

Figure 1. In the preparation phase (left part of the figure), participants stand naturally on the force plate (D and E). The pusher holds the force sensor on their dominant hand (A) and pushes the participant in front between their shoulder blades. The EMG electrodes are placed on the TA and SOL muscles of both participants (B and C). In the strong push condition, the faller needs to make a step to maintain balance (right part of the figure).

2.1.3. Detailed description of experiments

The experiment consisted of three sequential perturbation training sessions. Each session had different pushing force intensity (light, strong or medium push). Before the experiment, the pusher was instructed about the three levels of pushing force magnitude i.e., light, medium, and strong. In order to help the pusher to allocate the magnitude, a light push was described as causing a small swing of the faller, a medium push was described as causing a strong swing of the faller while still manageable to maintain balance, and a strong push was described as causing the faller to lose balance and a need to take a step to regain their balance. Under light and medium push conditions, the faller was asked to use a non-stepping postural control strategy to maintain balance, while under strong push condition, the faller was asked to use a stepping postural control strategy to maintain balance. The pushers were instructed to push onto the center of the upper back between the shoulder blades of the fallers.

Each push intensity was repeated 15 times, with random break time in between (8-15 s after both participants assumed the initial position). Between each push intensity there was a 10 min break. Push intensity was randomized across the participants.

2.1.4. Data processing applied and data storage

EMG signals were band-pass filtered (zero lag, 4th order Butter-worth filter with cut-off frequencies of 10 and 500 Hz) and full-wave rectified.

Due to the difference in sampling rates between force plates, force sensor, and EMG electrodes, we downsampled the EMG data and upsampled the load cell data to match a sampling rate of 1000 samples/s. Besides, we manually synchronized the starting timestamp of each trial. Synchronization of sampling rates and starting timestamps were done by using Matlab R2022a.

Storage: all data is currently stored locally at the ULM University lab computers and lab cloud storage.

All data for each participant are stored in one Matlab 'mat' file. The mat files consist of a Matlab structure named 'trial'. Inside this structure, there are three fields – 'strong', 'medium' and 'light'. Each field contains 3 matrices with the raw data of 15 trials as described below (see Figure 2).

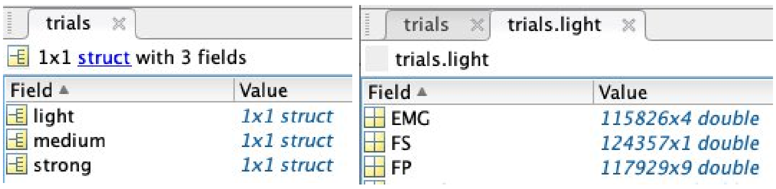

Figure 2. Matlab structure of the data file.

File naming – each file starts with 'sub' (subject), followed by the subject number (e.g., 1), followed by a hyphen and 'procdat'.
For example: sub1_procdata.mat

Description of data in the fields:

1. EMG
   This field includes the data of muscle activations of both participants (the pusher and the faller). Each column corresponds to individual muscle. Columns 1 and 2 belong to the faller and contain data of the SOL and GM muscles respectively. Columns 3 and 4 belong to the pusher and contain data of the SOL and GM muscles respectively. The unit of measurements is milli volts (mV).

2. FS
   This field contains the data from the force sensor which measured the force of the applied push. There is only 1 column with the data and the unit of measurements is newton (N).

3. FP
   This field contains the data of the ground reaction forces of both participants. The first column contains the time sequence, columns 2-4 contain ground reaction forces of the pusher (X - anterior/posterior force, Y – lateral force, Z – vertical force), columns 5-7 contain ground reaction forces of the faller (X - anterior/posterior force, Y – lateral force, Z – vertical force) and columns 8-9 contain the COP data of the faller (COP anterior/posterior, COP lateral).

2.1.5. Related publications (if applicable)

So far, the dataset was not described in a publication.

2.1.6. Data privacy and ethical approval

All participants had given their written consent to the data usage.

2.2. Controlled push of individual (ULM)

2.2.1. Objective

The second experiment was a follow-up of the first experiment. The goal of the second study remained the same as in the first study, i.e., to investigate the learning effects of perturbation training, however, with a different method of applying the perturbation. The reason for this change was due to high variability of both the perturbation intensity and perturbation profile between trials, which we observed in the first experiment. Namely the perturbation (i.e., the push) in the first experiment was subjectively set (and applied) and therefore not accurately controlled which led to a high variability in the responses of the fallers. Therefore, we designed and built a mechanical device (see Figure 3) which enabled us to as accurately as possible reproduce the perturbation (force and profile of the push) across multiple trials. Furthermore, the intensity of the push (pushing force) could now be individually set and manipulated by simply adding or removing weights. The pushing device works in a way that after a remotely controlled trigger is activated, a large handle is released which pushes a boxing sack mounted in front of the device. The boxing sack then pushes the participant who is standing in front of it.

Figure 3. Mechanical perturbation device.

2.2.2. Methods and types of data

We measured postural reactions of the participants during a balance perturbing experiment with two conditions.

By the time of writing this report, two healthy students (1 female, 1 male) from ULM University participated in this study as volunteers and had given their written consent to the data usage. Data collection started in December 2022 at the Applied Cognitive Psychology laboratory of ULM University and is still ongoing.

We collected the data of ground reaction forces, the pushing force and muscle activations. Ground reaction forces data with a sampling rate of 1000 samples/s were collected by two force plates (9260AA, Kistler Instrumente AG, Winterthur, Switzerland) placed under the feet the participant. The pushing force that the pushing machine applied onto the participant was measured with a 3-axis force sensor (45E15A, JR3, Woodland, CA, USA) mounted on the pushing device with a sampling rate of 1000 samples/s. The EMG electrodes were placed on muscles of both lower legs (GM, Gastrocnemius medialis). The myoelectric activity of those muscles was measured by using the Delsys Trigno Research+ System with a sampling rate of 2000 samples/s. Synchronization and triggering of all measurement devices was done by using an external hardware triggering device (E-DIO24, Measurement Computing Corporation, USA).

Figure 4. Experimental Setup. A participant is standing in front of the pushing machine, holding a joystick and engaging in a visuomotor task while waiting for the perturbation.

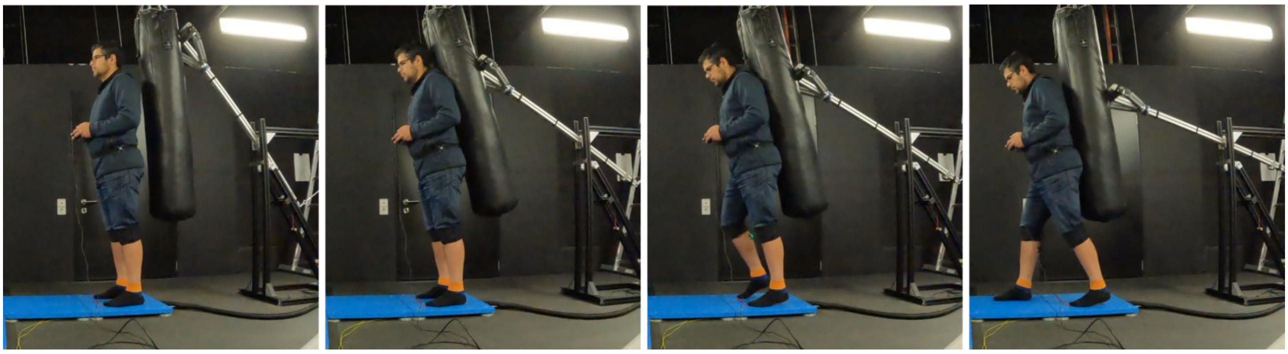

Figure 5. A sequence of one trial - waiting for a push while engaged in a visuomotor task, start of the push, start of the step, end of push and step.

2.2.3. Detailed description of experiments

The balance perturbing experiment was carried out with two conditions. In one condition the participant was standing freely and waiting to be pushed by the mechanical perturbation device. The task of the participant was to regain their balance as quickly as possible after the balance perturbation was imposed by the pushing device (see Figure 4). The perturbation intensity was set to a level so that the participant had to make a step forward to regain their balance after the perturbation (see Figure 5). In the other condition, we added a visuomotor task to distract the participant while they were waiting for the perturbation. With this condition we aimed to minimize the anticipatory part of postural control and focus more on the reactive part. The visuomotor task was a simple video game which was presented on screen in front of the participant. The participant used a joystick, held with both hands, to complete the task by pressing the buttons either with their left or right fingers, depending on the instructions displayed on screen.

Both conditions consisted of 25 consecutive trials and the order of the conditions was randomized across the participants. The perturbation intensity remained the same in both conditions and all trials. Between the conditions there was a 15 min break.

2.2.4. Data processing applied and data storage

EMG signals were band-pass filtered (zero lag, 4th order Butter-worth filter with cut-off frequencies of 10 and 500 Hz) and full-wave rectified.

Due to the sampling rate difference between force plates, force sensor, and EMG electrodes we downsampled the EMG data to 1000 samples/s. Data processing rates was realized by MatLab R2022a.

Storage: all data is currently stored locally at the ULM University lab computers and lab cloud storage.

File naming - data of each participant are stored in six individual Matlab '. mat' files (3 files per condition). The name of the .mat file describes the subject, experimental condition (1 = with the visuomotor task, 2 = no visuomotor task) and data stored in the file as follows:

S1C1_emg.mat = subject 1, condition 1, muscle activations data
S1C1_pert.mat = subject 1, condition 1, perturbation data
S1C1_cop.mat = subject 1, condition 1, ground reaction forces data

Description of data in the fields:

Each .mat file contains a Matlab structure with 25 fields. Each field of data contains several columns of data of an individual trial.

1. emgProc (in the muscle activations data file)
   The emgProc structure (see Figure 6) contains 25 fields with 4 columns of data. Field 'filt' contains 2 columns of filtered emg data (column1, GM left leg; column 2, GM right leg). Field 'rect' contains 2 columns of the rectified signals of emg data (column1, GM left leg; column 2, GM right leg). Field 'env' contains 2 columns of the calculated envelope over the rectified emg data (column1, GM left leg; column 2, GM right leg).

2. fpProc (in the ground reaction forces data file)
   The fpProc structure (see Figure 7) contains 25 fields with 1 column of data. Field 'fp' contains 17 columns of data of both force plates. The first column contains the time stamp, columns 2-9 contain data of the first force plate and columns 10-17 contain data of the second force plate. For each force plate the data in the columns correspond to the following variables: ground reaction force X direction, ground reaction force Y direction, ground reaction force Z direction, ground reaction torque X direction, ground reaction torque Y direction, ground reaction torque Z direction, center of pressure X, center of pressure Y.

3. fPert (in the perturbation data file)
   The fPert structure (see Figure 8) contains 25 fields with 1 column of data. Field 'pert' contains 7 columns of data corresponding to the following variables: force in X direction, force in Y direction, force in Z direction, torque in X direction, torque in Y direction, torque in Z direction, calculated force magnitude (calculated from all 3 forces and all 3 torques).

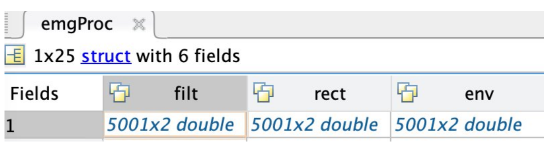

Figure 6. Structure of the file containing muscle activations data.

Figure 7. Structure of the file containing ground reaction forces data.

Figure 8. Structure of the file containing perturbation forces data.

2.2.5. Related publications (if applicable)

So far, the dataset was not described in a publication.

2.2.6. Data privacy and ethical approval

All participants had given their written consent to the data usage.

2.3. Individual Stability experiments (Rennes)

2.3.1. Objective

The objective of these experiments was to study the effect of the angle and the level of awareness to upcoming perturbations on the stability and recovering strategies of standing individuals.

2.3.2. Methods and types of data

The experiment consisted of recording the motion of participants following external perturbations. Different angles of perturbation have been tested together with different levels of awareness to the upcoming perturbations. During the experiment, participants received the following instructions: (1) Stand still and look straight ahead, with feet side by side in a stance not wider than hip-width. (2) Maintain a stable final position after the perturbation until the end of the recording. After the experiment Participants were ask to fill a questioner to assess their laterality (Coren 1993)(see Figure 9).

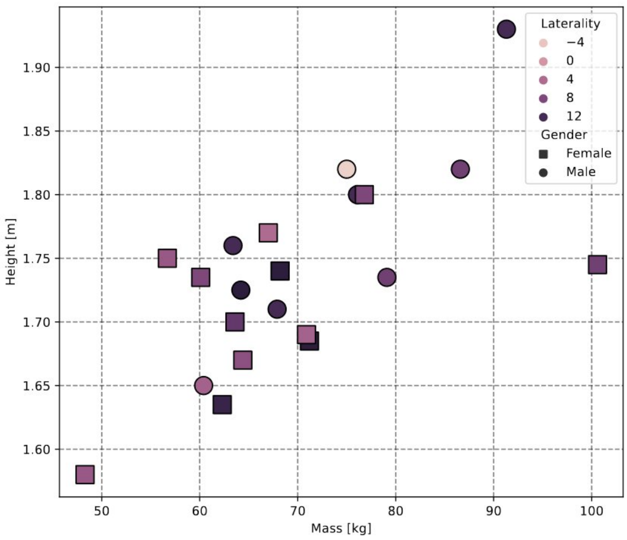

Figure 9. Participant mass and height with color relative to their laterality test score. Mean and std values: mass - 70.2±12.1 kg, height - 1.74±0.08

2.3.3. Detailed description of experiments

The experiment took place in Rennes between the 7th and 12th January 2021 and was carried out by INRIA. It involved a panel of 21 healthy young adults who participated in the study (10 females, 11 males). All participants signed an informed consent form relative to the processing of the data.

On one hand the effect of perturbation angles was tested using five different perturbations angles (see Figure 11). On the other hand, the level of awareness to upcoming perturbation was controlled using a sensory impairment device (see Figure 10). Two blocks of 30 trials were performed by the participants, one block wearing the sensory impairment and one without any sensory impairment.

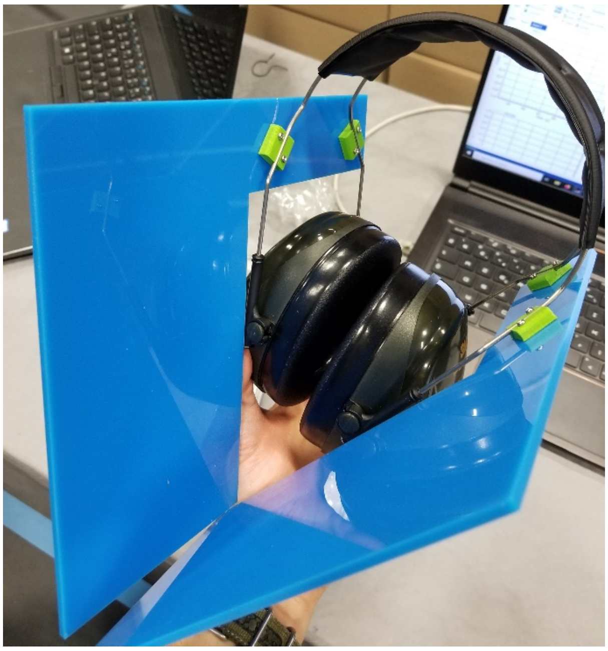

Figure 10. Picture of the sensory impairment device used during the experiments in order to change the level of awareness of participants regarding upcoming perturbations. The device was composed of a noise canceling headset with mounted plastic sheet on the side

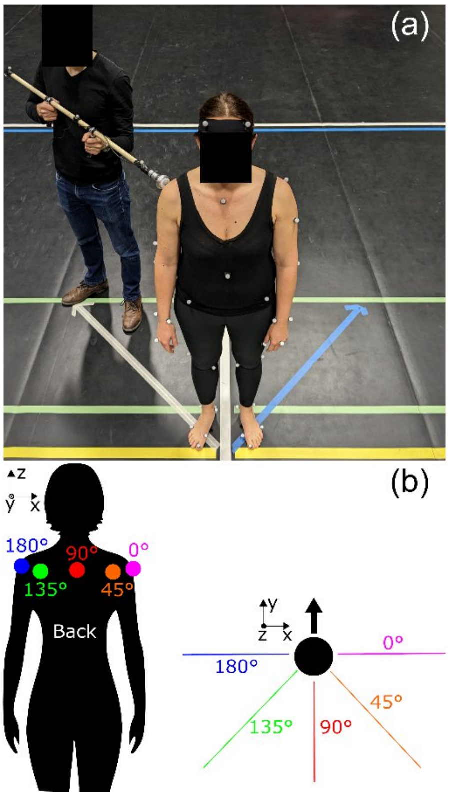

Figure 11. (a) Illustrative picture taken as the participant was about to receive a perturbation with an angle of 45◦. (b) Locations and angles of application points of the perturbations.

For each participant the experiment was divided in two sensory conditions blocks. During each experimental block a trial corresponded to the recording of a single reaction to an external perturbation. This external perturbation was applied by an experimenter using a pole equipped with a unilateral force sensor (U9C 0.5kN, HBK) followed by a rounded steel plate (see Figure 11a). The perturbations occurred at shoulder height at five different angles, with intensities divided into three ranges (`Low', `Medium', `High'). Each perturbation lasted for 0.74±0.14s. The perturbations were sharp bell shaped with average maximal intensities of 54±12N, 68±13N and 88±20N for `Low', `Medium' and `High' intensities respectively. Intensities were selected to ensure balance recovery with and without steps, based on the literature and observations during pilot experiments.

Participants underwent six perturbations at all of the five angles. All trials were performed in a randomized order. Hence, 30 trials were recorded in each block for a total of 60 trials per participants. The experiments led to the recording of 1260 trials.

Participants motion was recorded using 45 reflective markers and a 23 Qualisys camera system. The markers were placed on participants following standardized anatomical landmarks.

2.3.4. Data processing applied and data storage

The Motion captured data were exported into "c3d" files using the Qualisys motion cation system software. This format is classically used to deal with motion captured or animated character body. This allowed us to process the data using the open source CusToM Matlab library in order to fit biomechanical models to the recorded body motion. Using inverse kinematic we were then able to have access to kinematic quantities such as the center of mass of the participant or the evolution of their kinematic energy over time.

The data are currently stored on physical hard drives at INRIA as well as on the online platform Alfresco provided by INRIA which is the main storage support for heavy dataset in the frame of CrowdDNA project.

2.3.5. Related publications (if applicable)

An article entitled "Step triggering of young adults undergoing sudden external perturbation from different directions" is currently under reviews for the Journal of Biomechanics.

2.3.6. Data privacy and ethical approval

The experiment received approval from the French national ethics committee (*Comité de Protection des Personnes EudraCT: 2021-A01378-33*). All participants signed an informed consent form relative to the processing of the data and agreed to the publication and storage of there data after been anonymized.

2.4. Small-Scale Pushing Experiments (FZJ)

2.4.1. Objective

The experiments were conducted at the reseach centre in Jülich in April 2021. On this project, partners from FZJ and ULM worked together. The experiments can be divided into experiments with and without waiting time.

The aim of the experiments without waiting time was to link pressure data with motion data by investigating the forward propagation of a push through a row of five people. We are interested in the motor reactions of the persons and want to categorize the strength of the given impulses.

During the waiting experiments, the time before the push was important and the objective was to investigate if participants notice when one person in the row start to prepare him/herself for the push (i.e., stand straight, feet firmly on the ground, concentrated) and start to prepare themselves. In other words, we wanted to investigate if preparation behavior propagates through a row.

2.4.2. Methods and types of data

For the experiment, volunteers between the ages of 19 and 55 were recruited. To pass on the initial push, one of the experimenters used a punching bag that was hanging horizontally from the ceiling (see Figure 12) and pushed it in a controlled manner towards the back of the first participant in the row (left). A pressure sensor from Xsensor (LX210:50.50.05) was attached to the front of the punching bag in order to quantify the intensity of each initial push afterwards. The experiments were filmed by an overhead and a sideview camera. All participants wore an orange hat with an Aruco marker on top which is used for automatic detection of the individual head position from overhead video recordings. Furthermore, they were wearing inertial motion capturing (MoCap) suits by Xsens to track the individual full body motion. For safety reasons, the experimental area was laid out with judo mats, which we assume has a negligible effect on the natural movements. In some trials, the row stood in front of a wall where another pressure sensor (Pressure Mapping Sensor 5400N from Tekscan) was attached to. ECG sensors (heart rate) by Movisens, stopwatches and questionnaires were used during the waiting experiments.

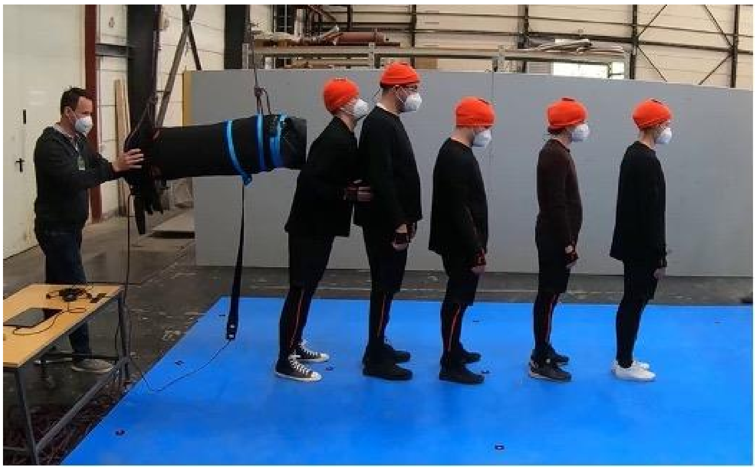

Figure 12. Example of the pushing experiment. The experimenter pushes the first person (left) with the punching bag at shoulder height. The participants are standing with elbow distance, hands down.

2.4.3. Detailed description of experiments

Five participants lined up as a queue in front of the punching bag, where the distance between individuals was adjusted based on their individual arm lengths (arms stretched out, elbow length, or as close as possible). Then the person standing directly at the punching bag was pushed forward in a controlled manner.

Varied parameters were as follows:

- Intensity of push: weak, medium, strong.
- Height of push: shoulder, lower back.
- Inter-person distance: none, elbow, arm.
- Initial arm position: free, down, up.
- Body posture: tension, relaxed.
- Boundary: none, wall.

A detailed list of performed parameter variations for exemplary trials can be found in Table 1. A complete table with all trials can be found in the Annex A.

In the waiting experiments, the push from behind was delayed and participants were not informed about the exact time of the push in order to study the propagation of preparation behavior. At the beginning of each trial, the participants and the experimenter each started a stopwatch and the participants were instructed to hit the stopwatch when they thought the push was about to come. What they did not know is that there was a confederate in the row who got a secret sign about 15 sec before the push and started preparing for it (i.e., stand straight, feet firmly on the ground, concentrated). Whether this preparation behavior was noticed by others was measured by observation, the time at which the stopwatch was hit, a questionnaire afterward, and heart rate data.

It was always pushed at shoulder height with a medium intensity. Following parameter were varied:

- Waiting time: 1 – 2.5 min.
- Inter-person distance: none, elbow.
- Position of secret sign: first, middle or last person.

Table 2 lists the performed variations for exemplary trials of the waiting time experiments. A complete table with all trials can be found in the Annex B.

Table 1. List of performed trials for pushes at shoulder height, no boundary, with tension in the body, i.e. feet parallel and arms free.

Block	Boundary	No	Intensity	Height	Orientation	Body posture	Inter-person distance	Arm position	Name
Tue_15	none	1	Weak	Shoulder	Back	Parallel	Elbow	free	Tue_15_m_noW_row2_01_w_s_b_p_e_f
Tue_15	none	2	Weak	Shoulder	Back	Parallel	Arm	free	Tue_15_m_noW_row2_02_w_s_b_p_a_f
Tue_15	none	3	Weak	Shoulder	Back	Parallel	None	free	Tue_15_m_noW_row2_03_w_s_b_p_n_f
Tue_15	none	4	Medium	Shoulder	Back	Parallel	Elbow	free	Tue_15_m_noW_row2_04_m_s_b_p_e_f
Tue_15	none	5	Medium	Shoulder	Back	Parallel	Arm	free	Tue_15_m_noW_row2_05_m_s_b_p_a_f
Tue_15	none	6	Medium	Shoulder	Back	Parallel	None	free	Tue_15_m_noW_row2_06_m_s_b_p_n_f
Tue_15	none	7	Strong	Shoulder	Back	Parallel	Elbow	free	Tue_15_m_noW_row2_07_s_s_b_p_e_f
Tue_15	none	8	Strong	Shoulder	Back	Parallel	Arm	free	Tue_15_m_noW_row2_08_s_s_b_p_a_f
Tue_15	none	9	Strong	Shoulder	Back	Parallel	None	free	Tue_15_m_noW_row2_09_s_s_b_p_n_f

Table 2. Exemplary list of variations for waiting experiment. It was always pushed with a medium intensity (m), at shoulder height (s), the back of the person (b) and posture as well as arm position were free (f).

Block	No	Intensity	Height	Orientation	Posture	Distance	Arm	Position sign	Time sign	Name
Tue_17	1	m	s	b	f	Elbow	f	Middle	1:40	Tue_17_wait1_01_m_s_b_f_e_f_m_140
Tue_17	2	m	s	b	f	Elbow	f	First	2:10	Tue_17_wait1_02_m_s_b_f_e_f_f_210
Tue_17	3	m	s	b	f	Elbow	f	Middle	1:55	Tue_17_wait1_03_m_s_b_f_e_f_m_155

Tue_17	4	m	s	b	f	Elbow	f	Last	2:30	Tue_17_wait1_04_m_s_b_f_e_f_l_230
Tue_17	5	m	s	b	f	Elbow	f	First	2:20	Tue_17_wait1_05_m_s_b_f_e_f_f_220
Tue_17	6	m	s	b	f	Elbow	f	Last	1:30	Tue_17_wait1_06_m_s_b_f_e_f_l_130
Tue_17	7	m	s	b	f	None	f	First	1:45	Tue_17_wait1_07_m_s_b_f_n_f_f_145
Tue_17	8	m	s	b	f	None	f	Last	2:15	Tue_17_wait1_08_m_s_b_f_n_f_l_215
Tue_17	9	m	s	b	f	None	f	Middle	2:05	Tue_17_wait1_09_m_s_b_f_n_f_m_205
Tue_17	10	m	s	b	f	None	f	Last	1:35	Tue_17_wait1_10_m_s_b_f_n_f_l_135
Tue_17	11	m	s	b	f	None	f	First	2:25	Tue_17_wait1_11_m_s_b_f_n_f_f_225
Tue_17	12	m	s	b	f	None	f	Middle	2:00	Tue_17_wait1_12_m_s_b_f_n_f_m_200

2.4.4. Data processing applied and data storage

The data processing for the small-scale pushing experiments (excluding the heart rate data) is completed. For the automatic extraction of head trajectories from video recordings the software PeTrack was used. Afterwards, the trajectories were manually corrected and saved in txt files. The MoCap data was pre-processed in the MVN Analyze Software and exported to mvnx as well as c3d data. These files contain the orientation, position, velocity, acceleration, angular velocity and angular acceleration of all 17 segments in addition to the joint angles and the position of the center of mass. The c3d data was fused with the head trajectories in order to gain a complete data set of the 3D full body motion of every person (from MoCap) with a position in space being as accurate as possible (from head trajectories). The pressure data is cut to each trial and saved as txt files, which include pressure values of each sensel, sensor information and an estimated load for all frames. The questionnaire data as well as the times of the stop watches were digitized and stored as pdf files. The heart rate data is stored as raw data.

All data is stored on a local server and on Alfresco. The data excluding the waiting time experiments are publicly available on the Pedestrian Dynamics Data Archive of the FZJ[1].

2.4.5. Related publications (if applicable)

A paper entitled "Forward Propagation of a push through a row of people" was accepted by the Journal Safety Science.

[1] *https://doi.org/10.34735/ped.2022.2.*

2.4.6. Data privacy and ethical approval

Ethical approval for this experiment was granted by the ethics board at the University of Wuppertal, Germany in April 2021 (Reference: MS/BBL 210409 Seyfried). Every person gave informed written consent before participation which included

- Participating voluntary in the study.
- Participation can be withdrawn at any time and without giving any reasons. It is also possible to omit individual trials without stopping the entire experiment.
- Minimum age of 18 years and a recommended maximum age of 60.
- Good knowledge of English language.
- Body height of 1.5 m to 2.0 m.
- Feeling physically fit enough, not being pregnant, having no physical impairment.
- Agreeing to be filmed and the material to be published in a data repository or used for (social) media.
- Wearing dark clothes and not wearing large bag/backpacks.

At the time of the experiments, Covid-19 regulations were still effective in Germany. Therefore, all participants had to wear masks.

2.5. Small-Scale Contact Experiments (URJC)

2.5.1. Objective

The main objective of these experiments was to capture high-quality close-interaction data that could be used in WP3 to build prediction models. When we talk about close-interaction data we refer to motion capture data that registers interactions at the individual's surface level. Therefore, we require measurements that are accurate up to a few centimeters.

2.5.2. Methods and types of data

We conducted a pilot study on which five volunteers (all of them are members of partners of the project) had to perform different interactions in groups of 2, 3 and 5 people. We also recorded multimodal data using different devices:

1. In our setup we used 6 cameras Gopro Hero 9 to record 4k multi-view video (see Figure 13). These cameras were distributed around a circle centered at the interaction area. For synchronization, we used the Android application "Tools for Hero" which allows starting the recording on the multiple cameras simultaneously. Moreover, a Tentacle Synchronization timecode was also filmed during each experiment to allow the synchronization with the other capture devices.

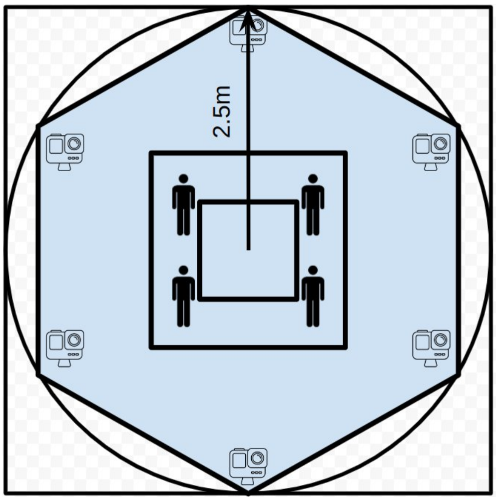

Figure 13. Camera layout for the Small-Scale contact experiments.

2. Each of the 5 volunteers wore an inertial motion capturing (MoCap) suits by Xsens to track the individual full body motion (see Figure 14). The data generated by these suits was also synchronized using the Tentacle Synchronization timecodes.
3. Each volunteer wore a helmet with several infrared markers forming a pattern. These markers were recorded by the Qualisys motion capture system, which allowed extracting head orientations and trajectories.

Figure 14. Photo of the experiments layout and volunteers wearing the XSens suites.

2.5.3. Detailed description of experiments

The experiments were conducted in the facilities of INRIA in Rennes between the 10th and 12th of January 2023. We recruited a total of 5 participants (3 male, 2 female) and recorded several interaction between groups of 2, 3 and 5 people:

1. **2-people experiments:** we recorded a total of 8 sequences of different pairs of subjects performing the following interactions:
    a. Frontal hug (see Figure 15).
    b. Back hug.
    c. Frontal push.
    d. Back push.
    e. Side push right.
    f. Side push left.
    g. Back bump right.
    h. Back bump left.

Figure 15. A pair of participants recorded by the 6 cameras while hugging each-other.

2. **3-people experiments:** in this experiment one personal had to walk through the middle of two people standing close to each-other. We recorded several permutations between the participants.
3. **5-people experiments:** we recorded two types of sequences featuring the 5 participants in the experiments. First we made the five participants stand in a row and asked the first one to push the others. The aim was recording how the push propagates through the row of participants and we recorded several permutations of them. Second, we asked 3 participants to stand close to each-other forming a triangle formation. then we asked the 2 remaining one to walk through them at the same time. Similarly, several permutations between the participants were recorded.

2.5.4. Data processing applied and data storage

The processing of the data for the small-scale interaction experiments is still not finished. Several steps have been carried out in order to reconstruct meaningful data from the raw sources and some final refinement is still needed.

1. The first step consisted on fitting a parametric surface model (SMPL) the point cloud outputted by the XSens software.We used the publicly available tool Mosh++ for this task. We started by manually fitting the shape of the model to the body measurements provided by each of the participants. Then we built a mapping between the points provided by the XSens software (bio-mechanical joints) and the vertices of the model. Finally, we ran the optimization software to recover the pose of the models for the whole Mocap sequences (see Figure 16).
2. Inertial tracking devices tend to introduce a drift on the position of the tracked points with time. Moreover, each individual is recorded in its own reference frame of coordinates.Therefore our second step consists of using the position and orientations of the helmets tracked using the Qualysis system to place all the interacting individuals in the same reference frame.

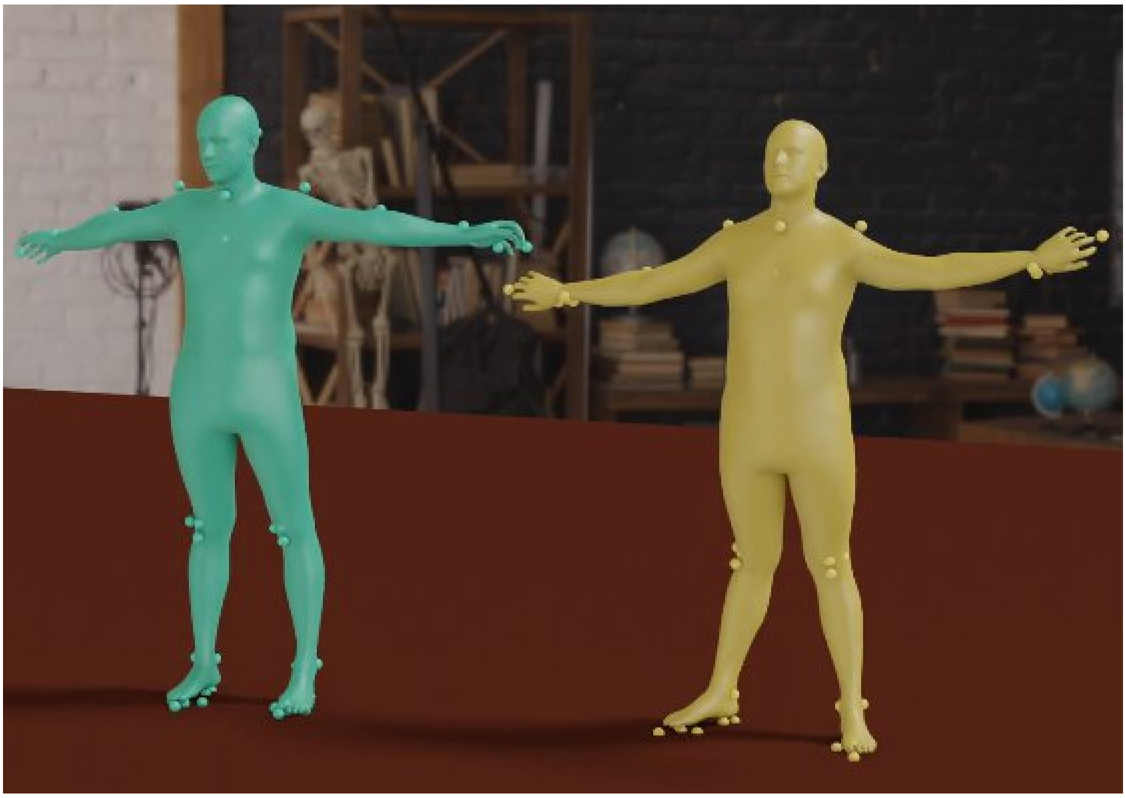

Figure 16. An example of the points provided by XSens superposed on top of the parametric surface models estimated for two participants.

Regarding the data storage, the XSens and Qualysis data is currently stored in c3d format on the online platform Alfresco provided by INRIA which is the main storage support for heavy dataset in the frame of CrowdDNA project. The video data and the reconstructed surface data is currently stored on physical hard drives at URJC, and they will be uploaded to Alfresco once the processing has finished.

Conclusion

At the time of publication of this report, all planned experiments were successfully performed. During the third period, further efforts will be made to fulfill the objectives of WP1 and the project. The goal to design models of local physical interaction will be served by all experiments presented in this deliverable being studies with only a single participant being perturbed as well as the small group experiments in which either a small group was being perturbed or interactions were recorded. The small group experiments also serve the objective the study the relations between macroscopic features (such as the density) with microscopic features of the individuals on limb scale (such as their balance recovery and their interactions). It has to be noted that the individual balance recovery experiments also serve as a validation and a comparison between different scenarios.

ANNEX A - Overview small pushing experiments

Block	Pushing	Boundary	Experiment	Run number	Intensity	Height	Orientation	Body Posture	Inter-person Distance	Arm Position	Run Name
Tue_15	manually	none	row2	1	weak	shoulder	back	parallel	elbow	free	Tue_15_m_noW_row2_01_w_s_b_p_e_f
	manually	none	row2	2	weak	shoulder	back	parallel	arm	free	Tue_15_m_noW_row2_02_w_s_b_p_a_f
	manually	none	row2	3	weak	shoulder	back	parallel	none	free	Tue_15_m_noW_row2_03_w_s_b_p_n_f
	manually	none	row2	4	medium	shoulder	back	parallel	elbow	free	Tue_15_m_noW_row2_04_m_s_b_p_e_f
	manually	none	row2	5	medium	shoulder	back	parallel	arm	free	Tue_15_m_noW_row2_05_m_s_b_p_a_f
	manually	none	row2	6	medium	shoulder	back	parallel	none	free	Tue_15_m_noW_row2_06_m_s_b_p_n_f
	manually	none	row2	7	strong	shoulder	back	parallel	elbow	free	Tue_15_m_noW_row2_07_s_s_b_p_e_f
	manually	none	row2	8	strong	shoulder	back	parallel	arm	free	Tue_15_m_noW_row2_08_s_s_b_p_a_f
	manually	none	row2	9	strong	shoulder	back	parallel	none	free	Tue_15_m_noW_row2_09_s_s_b_p_n_f
	manually	none	row2	10	weak	shoulder	back	parallel	elbow	down	Tue_15_m_noW_row2_10_w_s_b_p_e_d
	manually	none	row2	11	weak	shoulder	back	parallel	elbow	down	Tue_15_m_noW_row2_11_w_s_b_p_e_d
	manually	none	row2	12	weak	shoulder	back	parallel	arm	down	Tue_15_m_noW_row2_12_w_s_b_p_a_d
	manually	none	row2	13	weak	shoulder	back	parallel	arm	down	Tue_15_m_noW_row2_13_w_s_b_p_a_d
	manually	none	row2	14	weak	shoulder	back	parallel	none	down	Tue_15_m_noW_row2_14_w_s_b_p_n_d
	manually	none	row2	15	weak	shoulder	back	parallel	none	down	Tue_15_m_noW_row2_15_w_s_b_p_n_d
	manually	none	row2	16	medium	shoulder	back	parallel	elbow	down	Tue_15_m_noW_row2_16_m_s_b_p_e_d
	manually	none	row2	17	medium	shoulder	back	parallel	elbow	down	Tue_15_m_noW_row2_17_m_s_b_p_e_d
	manually	none	row2	18	medium	shoulder	back	parallel	arm	down	Tue_15_m_noW_row2_18_m_s_b_p_a_d
	manually	none	row2	19	medium	shoulder	back	parallel	arm	down	Tue_15_m_noW_row2_19_m_s_b_p_a_d
	manually	none	row2	20	medium	shoulder	back	parallel	none	down	Tue_15_m_noW_row2_20_m_s_b_p_n_d
	manually	none	row2	21	medium	shoulder	back	parallel	none	down	Tue_15_m_noW_row2_21_m_s_b_p_n_d
	manually	none	row2	23	weak	shoulder	back	parallel	elbow	up	Tue_15_m_noW_row2_23_w_s_b_p_e_u
	manually	none	row2	24	weak	shoulder	back	parallel	elbow	up	Tue_15_m_noW_row2_24_w_s_b_p_e_u
	manually	none	row2	25	weak	shoulder	back	parallel	arm	up	Tue_15_m_noW_row2_25_w_s_b_p_a_u
	manually	none	row2	26	weak	shoulder	back	parallel	arm	up	Tue_15_m_noW_row2_26_w_s_b_p_a_u
	manually	none	row2	27	weak	shoulder	back	parallel	none	up	Tue_15_m_noW_row2_27_w_s_b_p_n_u
	manually	none	row2	28	weak	shoulder	back	parallel	none	up	Tue_15_m_noW_row2_28_w_s_b_p_n_u
	manually	none	row2	29	medium	shoulder	back	parallel	elbow	up	Tue_15_m_noW_row2_29_m_s_b_p_e_u
	manually	none	row2	30	medium	shoulder	back	parallel	elbow	up	Tue_15_m_noW_row2_30_m_s_b_p_e_u
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	manually	none	row2	33	medium	shoulder	back	parallel	none	up	Tue_15_m_noW_row2_33_m_s_b_p_n_u
	manually	none	row2	34	medium	shoulder	back	parallel	none	up	Tue_15_m_noW_row2_34_m_s_b_p_n_u
	manually	none	row2	35	strong	shoulder	back	parallel	elbow	up	Tue_15_m_noW_row2_35_s_s_b_p_e_u
	manually	none	row2	36	strong	shoulder	back	parallel	elbow	up	Tue_15_m_noW_row2_36_s_s_b_p_e_u
	manually	none	row2	37	strong	shoulder	back	parallel	arm	up	Tue_15_m_noW_row2_37_s_s_b_p_a_u
	manually	none	row2	38	strong	shoulder	back	parallel	arm	up	Tue_15_m_noW_row2_38_s_s_b_p_a_u
	manually	none	row2	39	strong	shoulder	back	parallel	none	up	Tue_15_m_noW_row2_39_s_s_b_p_n_u
	manually	none	row2	40	strong	shoulder	back	parallel	none	up	Tue_15_m_noW_row2_40_s_s_b_p_n_u
	manually	none	row2	41	strong	shoulder	back	parallel	elbow	down	Tue_15_m_noW_row2_41_s_s_b_p_e_d
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	manually	none	row2	43	strong	shoulder	back	parallel	arm	down	Tue_15_m_noW_row2_43_s_s_b_p_a_d
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	manually	none	row2	45	weak	lower back	back	parallel	elbow	free	Tue_15_m_noW_row2_45_w_l_b_p_e_f
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	manually	none	row2	48	medium	lower back	back	parallel	elbow	free	Tue_15_m_noW_row2_48_m_l_b_p_e_f
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	manually	none	row2	50	medium	lower back	back	parallel	arm	free	Tue_15_m_noW_row2_50_m_l_b_p_a_f
	manually	none	row2	51	medium	lower back	back	parallel	arm	free	Tue_15_m_noW_row2_51_m_l_b_p_a_f
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	manually	wall	row4	51	weak	shoulder	back	parallel	arm	down	Wed_03_m_wiW_row4_51_w_s_b_p_a_d
	manually	wall	row4	52	medium	shoulder	back	parallel	arm	down	Wed_03_m_wiW_row4_52_m_s_b_p_a_d
	manually	wall	row4	53	medium	shoulder	back	parallel	arm	down	Wed_03_m_wiW_row4_53_m_s_b_p_a_d
	manually	wall	row4	54	strong	shoulder	back	parallel	arm	down	Wed_03_m_wiW_row4_54_s_s_b_p_a_d
	manually	wall	row4	55	strong	shoulder	back	parallel	arm	down	Wed_03_m_wiW_row4_55_s_s_b_p_a_d
	manually	wall	row4	56	weak	shoulder	back	parallel	arm	up	Wed_03_m_wiW_row4_56_w_s_b_p_a_u
	manually	wall	row4	57	weak	shoulder	back	parallel	arm	up	Wed_03_m_wiW_row4_57_w_s_b_p_a_u
	manually	wall	row4	58	medium	shoulder	back	parallel	arm	up	Wed_03_m_wiW_row4_58_m_s_b_p_a_u
	manually	wall	row4	59	medium	shoulder	back	parallel	arm	up	Wed_03_m_wiW_row4_59_m_s_b_p_a_u
	manually	wall	row4	60	strong	shoulder	back	parallel	arm	up	Wed_03_m_wiW_row4_60_s_s_b_p_a_u
	manually	wall	row4	61	strong	shoulder	back	parallel	arm	up	Wed_03_m_wiW_row4_61_s_s_b_p_a_u
	manually	wall	row4	62	weak	shoulder	back	relaxed	arm	free	Wed_03_m_wiW_row4_62_w_s_b_r_a_f
	manually	wall	row4	63	weak	shoulder	back	relaxed	arm	free	Wed_03_m_wiW_row4_63_w_s_b_r_a_f
	manually	wall	row4	64	medium	shoulder	back	relaxed	arm	free	Wed_03_m_wiW_row4_64_m_s_b_r_a_f
	manually	wall	row4	65	medium	shoulder	back	relaxed	arm	free	Wed_03_m_wiW_row4_65_m_s_b_r_a_f
Wed_04	manually	wall	row5	1	weak	shoulder	back	relaxed	none	free	Wed_04_m_wiW_row5_01_w_s_b_r_n_f
	manually	wall	row5	2	weak	shoulder	back	relaxed	none	free	Wed_04_m_wiW_row5_02_w_s_b_r_n_f
	manually	wall	row5	3	medium	shoulder	back	relaxed	none	free	Wed_04_m_wiW_row5_03_m_s_b_r_n_f
	manually	wall	row5	4	medium	shoulder	back	relaxed	none	free	Wed_04_m_wiW_row5_04_m_s_b_r_n_f
	manually	wall	row5	5	weak	lower back	back	parallel	elbow	free	Wed_04_m_wiW_row5_05_w_l_b_p_e_f
	manually	wall	row5	6	weak	lower back	back	parallel	elbow	free	Wed_04_m_wiW_row5_06_w_l_b_p_e_f
	manually	wall	row5	7	medium	lower back	back	parallel	elbow	free	Wed_04_m_wiW_row5_07_m_l_b_p_e_f
	manually	wall	row5	9	strong	lower back	back	parallel	elbow	free	Wed_04_m_wiW_row5_09_s_l_b_p_e_f
	manually	wall	row5	10	strong	lower back	back	parallel	elbow	free	Wed_04_m_wiW_row5_10_s_l_b_p_e_f
	manually	wall	row5	11	weak	lower back	back	parallel	arm	free	Wed_04_m_wiW_row5_11_w_l_b_p_a_f
	manually	wall	row5	12	weak	lower back	back	parallel	arm	free	Wed_04_m_wiW_row5_12_w_l_b_p_a_f
	manually	wall	row5	13	medium	lower back	back	parallel	arm	free	Wed_04_m_wiW_row5_13_m_l_b_p_a_f
	manually	wall	row5	14	medium	lower back	back	parallel	arm	free	Wed_04_m_wiW_row5_14_m_l_b_p_a_f

ANNEX B - Overview waiting time experiments

Block	Experiment	Run number	Intensity	Height	Orientation	Body Posture	Inter-person Distance	Initial Arm position	Position of Sign	Time of Sign	Run Name
Tue_17	wait1	1	medium	shoulder	back	free	elbow	free	middle	1:40	Tue_17_wait1_01_m_s_b_f_e_f_m_140
	wait1	2	medium	shoulder	back	free	elbow	free	first	2:10	Tue_17_wait1_02_m_s_b_f_e_f_f_210
	wait1	3	medium	shoulder	back	free	elbow	free	middle	1:55	Tue_17_wait1_03_m_s_b_f_e_f_m_155
	wait1	4	medium	shoulder	back	free	elbow	free	last	2:30	Tue_17_wait1_04_m_s_b_f_e_f_l_230
	wait1	5	medium	shoulder	back	free	elbow	free	first	2:20	Tue_17_wait1_05_m_s_b_f_e_f_f_220
	wait1	6	medium	shoulder	back	free	elbow	free	last	1:30	Tue_17_wait1_06_m_s_b_f_e_f_l_130
	wait1	7	medium	shoulder	back	free	none	free	first	1:45	Tue_17_wait1_07_m_s_b_f_n_f_f_145
	wait1	8	medium	shoulder	back	free	none	free	last	2:15	Tue_17_wait1_08_m_s_b_f_n_f_l_215
	wait1	9	medium	shoulder	back	free	none	free	middle	2:05	Tue_17_wait1_09_m_s_b_f_n_f_m_205
	wait1	10	medium	shoulder	back	free	none	free	last	1:35	Tue_17_wait1_10_m_s_b_f_n_f_l_135
	wait1	11	medium	shoulder	back	free	none	free	first	2:25	Tue_17_wait1_11_m_s_b_f_n_f_f_225
	wait1	12	medium	shoulder	back	free	none	free	middle	2:00	Tue_17_wait1_12_m_s_b_f_n_f_m_200
Wed_06	wait2	1	medium	shoulder	back	free	none	free	middle	1:15	Wed_06_wait2_01_m_s_b_f_n_f_m_115
	wait2	2	medium	shoulder	back	free	none	free	first	1:45	Wed_06_wait2_02_m_s_b_f_n_f_f_145
	wait2	3	medium	shoulder	back	free	none	free	middle	1:35	Wed_06_wait2_03_m_s_b_f_n_f_m_135
	wait2	4	medium	shoulder	back	free	none	free	last	1:05	Wed_06_wait2_04_m_s_b_f_n_f_l_105
	wait2	5	medium	shoulder	back	free	none	free	first	1:55	Wed_06_wait2_05_m_s_b_f_n_f_f_155
	wait2	6	medium	shoulder	back	free	none	free	last	1:30	Wed_06_wait2_06_m_s_b_f_n_f_l_130
	wait2	7	medium	shoulder	back	free	elbow	free	first	1:10	Wed_06_wait2_07_m_s_b_f_e_f_f_110
	wait2	8	medium	shoulder	back	free	elbow	free	last	1:40	Wed_06_wait2_08_m_s_b_f_e_f_l_140
	wait2	9	medium	shoulder	back	free	elbow	free	middle	1:25	Wed_06_wait2_09_m_s_b_f_e_f_m_125
	wait2	10	medium	shoulder	back	free	elbow	free	last	2:00	Wed_06_wait2_10_m_s_b_f_e_f_l_200
	wait2	11	medium	shoulder	back	free	elbow	free	first	1:50	Wed_06_wait2_11_m_s_b_f_e_f_f_150
	wait2	12	medium	shoulder	back	free	elbow	free	middle	1:00	Wed_06_wait2_12_m_s_b_f_e_f_m_100