Analysis of tri-axial accelerometer data of 4 month old infants

Student: Jerneja Mislej

University of Lund

bif15jmi@student.lu.se

Project supervisor: Frida Renstrom

University of Lund

Frida.Renstrom@med.lu.se

Assistant project supervisors: Paul W. Franks, Azra Kurbasic

University of Lund

Paul.Franks@med.lu.se

Azra.Kurbasic@med.lu.se

Abstract

The main goal of the project is to extract a measure of physical activity levels from tri-axial accelerometer data, taken of four month old infants and to assess the feasibility and validation of the extraction. Infants wore two accelerometers, one on the torso, other on the ankle, for 48 hours in a free living environment. In order to properly extract physical activity level data, the raw accelerometer output has to be prepared and preprocessed. Preparation includes data organization and timestamp alignment, while the preprocessing includes filtering, averaging, removal of non-wear time, summary measure derivation, correction for gravity component and correction for acceleration contributed by the infants caretaker. Several approaches are used and the performance of each discussed. The results from the correction of caretakers contributing accelerations are compared against the diary notations of the infant's sleeping and feeding habits, kept by their mothers. In the end, physical activity levels are extracted and analyzed along with other variables.

Contents

1 Introduction

The tri-axial accelerometer data was obtained in the Energy balance and health in pregnancy study, a pre-pilot study for LifeGene (http://www.lifegene.se). One of the aims of the pre-pilot study was to assess the feasibility of estimating physical activity (PA) in young infants in order to associate lifestyle behaviors during pregnancy and post-partum markers of infant cardiometabolic health. An extensive collection of characteristics was measured and obtained, including infant and maternal tri-axial accelerometer data and infant sleeping and feeding diaries. Mothers characteristics in pregnancy, along with the infants characteristics post-partum, can provide valuable information when studying fetal programming[14][15][16]. Infants at 4 months post-partum will not yet have been substantially exposed to and influenced by the environment outside the intrauterine environment, especially when it comes to PA, which is consequently more instinct at that point and can therefor be considered pre-programmed. By being able to accurately estimate infants PA, many research questions could be addressed.

In this project, estimation of infant PA is addressed along with an assessment of the feasibility regarding such an estimation. Although accelerometers are increasingly being used for PA estimations in population studies, their output needs to be interpreted with caution. Due to its properties and sensitivity, the accelerometer is prone to pick up accelerations not related to the PA of the subject wearing it. In measurements taken of adults, these are mainly due to gravitation and instrumentation noise, but in infants and smaller children who are less or not mobile in terms of walking, the caretaker contributes greatly to the acceleration by carrying or placing the child [1]. By not appropriately considering acceleration contributed by the caretaker, the extracted infant PA would incorrectly present infants that are moved around more as being more active.

For that purpose, the pre-pilot project was designed to place two accelerometers on the infant, one on the torso, other on the ankle. The rationale behind this was that infants at four months of age are unable to move the torso by themselves, so any large accelerations measured on the torso would consequently mean that the infant was being moved. On the other hand, the infant can move his legs, so having accelerations detected on the ankle accelerometer, but not on the torso, would mean the infant is being active by own account. At the same time, the mothers, who were the main caretakers of the infants in the present study, also wore a wrist accelerometer and kept a diary of feeding and sleeping habits of the infant, as well as other important information concerning the infant and the experiment.

2 Methods

Acceleration data was recorded in a free living environment, for 48 hours, using a tri-axial GENEA accelerometer (UniLever Ltd), sampled at 40 Hz and stored in g units. In order to properly analyze the tri-axial accelerometer data, preparation and preprocessing of the data needs to be performed. As the infant torso, infant ankle and maternal accelerometers did not start measuring at the exact same time, the measurements need to be aligned according to timestamps, to ensure they represent accelerations recorded at the same time. This is followed by accelerometer non-wear data removal, summary measure derivation and correction for the gravitational acceleration. In the last step of preprocessing, the contributing accelerations need to be addressed even further. Generally, accelerometers will record any movement, regardless whether the movement is due to PA of the subject wearing it or due to the subject being moved or carried, or even due to just readjustment of the accelerometer. The accelerometer data needs to be cleaned, so that the remaining accelerations are due to infants PA only. If the preprocessing and data cleaning is efficient, then infants PA can simply be extracted based on appropriate cut points for the standard deviation of the acceleration.

2.1 Timestamp alignment

The accelerometers were attached upon a visit to the research clinic. With few exceptions, accelerometers were set to start recording before being attached and were attached to the mothers wrist, infants torso and infants ankle one after the other. This resulted in different start timestamps. In order to ensure proper analysis of the data, the measurements needed to be aligned so that for each mother-infant pair, all three measurements had the same start timestamp. The alignment was done with a Python script that loaded and read all three files belonging to the measurements of each mother-infant pair, processed the data and saved the results. Files were loaded using the module *pandas*. The timestamps of the accelerometer were in the YYYY-MM-DD HH:MM:SS:ffff format and were parsed with the module *dateutil* which enables the resulting parsed timestamps to be simply compared with each other. The latest start timestamp was determined and converted back into the appropriate format with *strftime* from the *os* module. This timestamp was then located in the rest of the measurements which were truncated up to that index. The resulting three measurements were aligned according to the absolute timestamp and were saved, again using the module *pandas*.

2.2 Accelerometer non-wear time

With exception of the accelerometer placed on the infants ankle, the accelerometers could be removed and reattached. Mothers were asked to note such non-wear time in the diary. Prior to diary examination, non-wear time was detected automatically with a Pyhton script. The diary notations were then used for validation of the results. The Python script was designed based on previous approaches towards non-wear time removal [2]. The principal idea of the approach is to examine the standard deviation (SD) and the span between minimum and maximum of a windowed measurement and remove windows where the SD and span are below certain cut points defined in published methods [2]. To increase accuracy, the baseline of the windowed measurement is also examined in this project. When the accelerometer is not worn by the subject, it should only be picking up acceleration due to gravitation which is constant on one axis only. As a consequence, the measurement of non-wear time should in theory have none or very little SD, the span between the minimum value and the maximum value should be close to zero and the baseline of the measurement should be a flat line without any drift or jumps. But in practice, one cannot rely fully on these assumptions. All accelerometers have inherent noise, for the accelerometer used in the current project (GENEA), it has been shown that the SD of a motionless device is 2.6 mg. Other factors can also contribute towards the increased SD, since being in a free living environment, the accelerometers are liable to pick up the movement from the environment, even if only the surface on which it rests is being bumped into. On the other hand, if the accelerometer is not placed on the torso, it will not pick up accelerations due to heartbeats and chest movements from breathing, and can therefore appear as non-wear time when the subject is actually sleeping very still. All this has to be taken into consideration when extracting and removing the data of non-wear time and several parameters need to be set which greatly affect the final outcome. For this reason, some parameters were left to be passed on to the script upon run time in order to enable trial and examination. These parameters were:

- Window length
- SD threshold
- Span between minimum and maximum threshold

These parameters are read with the module *sys*. Data is loaded and read with the module *pandas*. Each of the three axis are filtered with a median filter of width 11, using *medfilt* from module *scipy.signal*. The measurement is windowed with a loop. For each window, SD and span between minimum and maximum is calculated. If these values are below the set thresholds, a line is fitted through the accelerometer data points of the window with the help of *polyfit* from the module *numpy*. The slope of the line should be near to zero. The value of *1e-07* was chosen as the threshold and if the absolute value of the slope was below that threshold, the window was classified as non-wear time. The data along with the results were plotted using module *matplotlib* and printed in the terminal, example in Figure 1.
Based on trial and examination of the results and the previously set cut points [2], the window length was set to 30 minutes, which corresponds to 72000 data points. Shorter windows were more prone to classify time windows of sleeping as non-wear

time, whereas larger windows failed to detect short duration of non-wear time. SD threshold was set to 0.002 g and minimum to maximum span threshold was set to 0.015 g. To increase accuracy even further, a more detailed windowed examination was performed around the edges to better detect the borders of the blocks of non-wear time, and up to three windows of in between blocks of non-wear time were set as non-wear. Upon final inspection of the results and their plots, all visually apparent non-wear blocks were detected, with a few minor blocks that were likely to be sleeping blocks based on the time of occurrence. All together 12 out of 30 infants had non-wear time detected on the torso accelerometer, with an average of 8.6% of data being removed with minimum 1.2% and maximum 31.1%. One of the infants had also had the ankle accelerometer removed at the end of the 48 hour time period. The data points from the non-wear time detected in infant ankle and torso placed accelerometer were removed from all measurements, while the data points from the non-wear time detected in the maternal accelerometer data were only removed from the maternal accelerometer data. The start and end timestamps of all blocks of data points detected as non-wear, were saved to enable validation against the diaries.

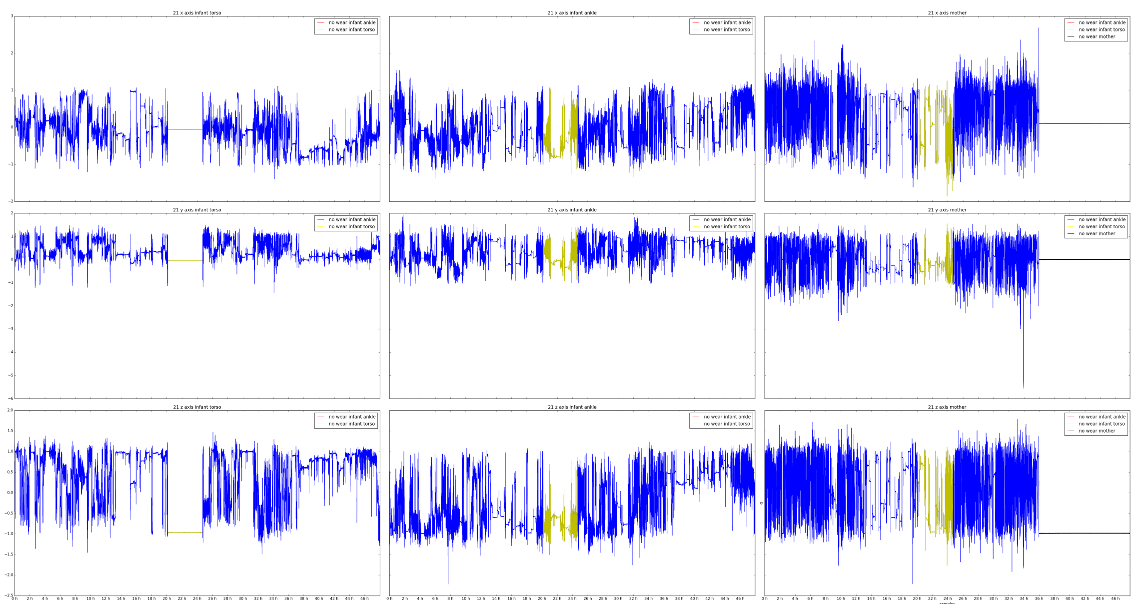


Figure 1: *Example of accelerometer data for one infant-mother pair. The x, y and z axis are aligned vertically, while the infant torso, infant ankle and mother wrist measurements are aligned horizontally. The yellow color represents infant torso non-wear time, which is subsequently colored in the rest of the measurements and the black color represents maternal non-wear time, which is colored only in maternal measurement.*

2.3 Summary derivation

Accelerometers can be designed to measure acceleration on a single axis, dual axes or three axes along with different sampling rates. For the accelerometer used in this project (GENEA), it has been shown that sampling frequencies larger than 10 Hz and/or more than one axis do not significantly increase classification accuracy, when classifying 10-12 semistructured activities performed in the laboratory or an outdoor environment, while wearing the accelerometer on the right wrist[7]. At the same time, having three axis and a high sampling rate, the amount of noise present in the final outcome can be higher, if the data is not filtered and summarized properly. Another issue arises when comparing the outcome of two accelerometers. The way the ankle and torso accelerometers were placed, the three axes of the two accelerometers were not aligned and with the mobility of the infants ankle they were liable to rotations. This presents a problem, since each of the axes should be aligned prior to the analysis. For the reasons given above, a summary over all three axis has to be derived. Summary derivation can have a significant impact on the final results. Although it has been shown that different summaries can have a similar PA prediction accuracy, the amount of variance interfered by summarization can differ significantly [3].
Two types of summary derivations were performed and examined in this project. First was the averaged Euclidean norm of the median filtered three axis, followed by a subtraction of one, to correct for the gravitation. Second was an averaged Euclidean norm of the Butterworth bandpass filtered and median filtered three axes.
Averaging was done over one second, with the purpose of removing the noise. The width of the median filter was 11 and its purpose was to remove any spikes from the measurement which are due to noise. Bandpass filter was set to allow frequencies from 0.5 to 15 Hz, since changes occurring at a faster paste then 15 times a second are most probably due to noise, while changes occurring slower then once per two seconds are actually baseline shifts due to rotations.
When plotting the derived summary for torso and ankle, one can clearly see the substantial similarities in the measurements due to the caretakers contributions, example for the first summary derivation in Figure 2.
While the infant torso and ankle derived summaries show substantial similarity, the corresponding derived summary, of the maternal accelerometer data, only exhibits the same pattern of activity as the infant during the night, indicating plausible interaction between the mother and her infant, example in Figure 3.

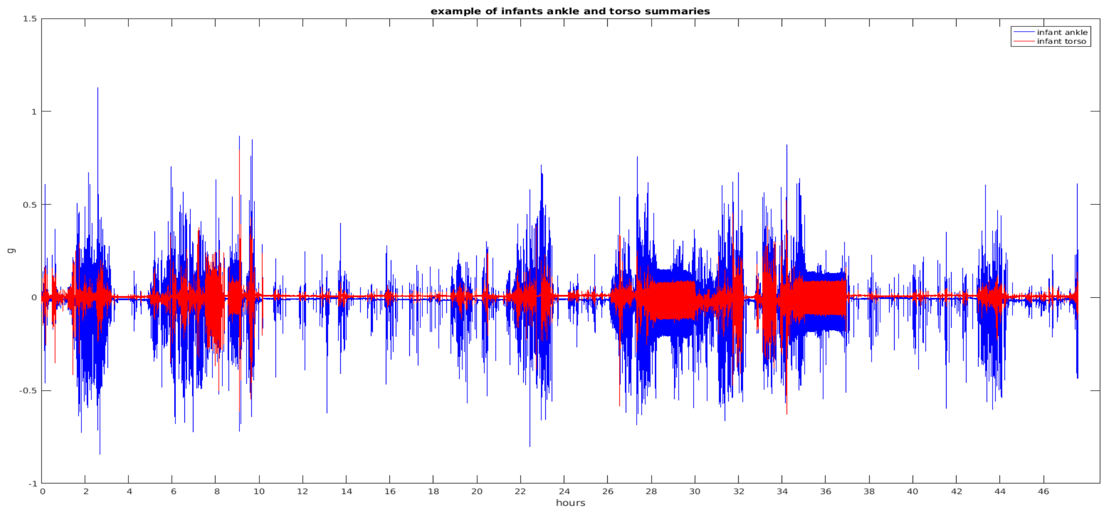


Figure 2: *An example of the first summary derivation over all three axes for infant torso and infant ankle measurement, illustrating the degree of similarity in activity patterns, with visible leftovers of the gravitational acceleration.*

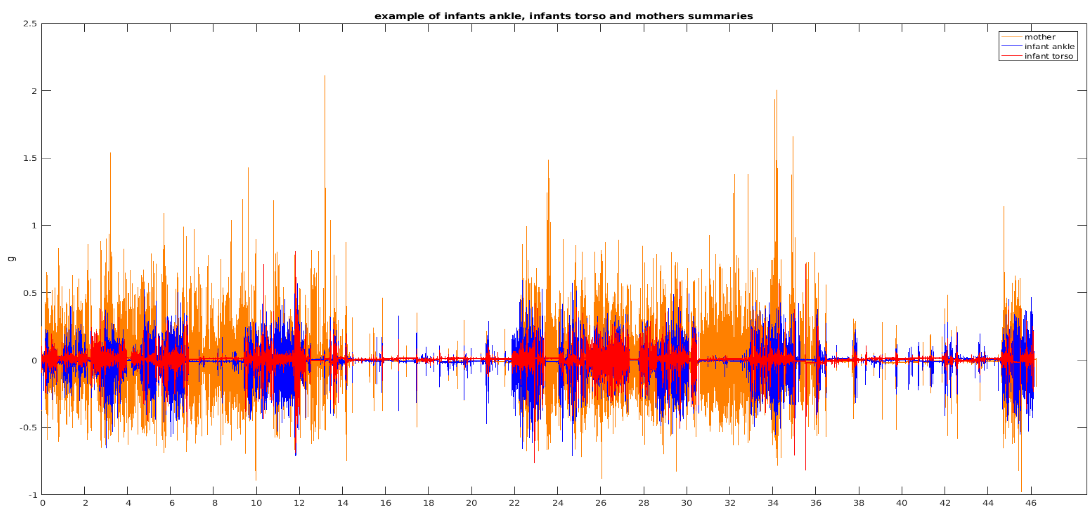


Figure 3: *An example of the first derived summaries of infant ankle, infant torso and maternal wrist measurements, illustrating the degree of similarity in activity patterns across night and day, with visible leftovers of the gravitational acceleration.*

In Figure 2 and 3 one can observe the remaining baseline shifts, due to leftovers of the gravitational accelerations in the first derived summary, that need further removal, which is discussed in the next subsection.
Although the principals in both summary derivations are commonly used in accelerometer data processing, they are fundamentally very different and so is their outcome. The lack of established consensus regarding an optimal summary derivation is an on-

going issue in accelerometer data processing and analysis. Same example as in Figure 2 is shown for the second summary derivation in Figure 4, showing substantial differences, which are expected, based on the fundamental differences of the principals used.

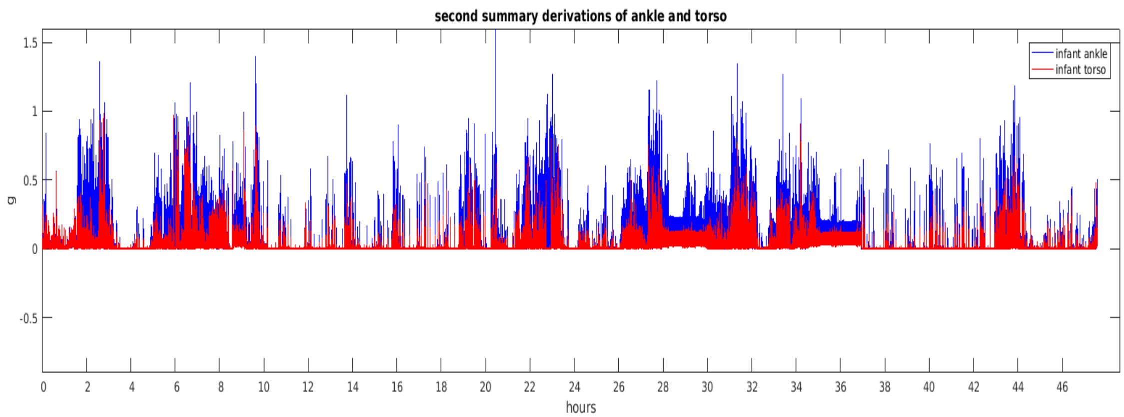


Figure 4: *An example of the second summary derivation over all three axes for infant torso and infant ankle measurement.*

The two different types of summary derivation were therefor included in the analyses in order to asses the amount of variance interfered and choose the best to use for PA extraction.

2.4 Gravity component

The separation and removal of the gravitational component becomes more complicated when rotations are present in the measurement [3]. This can result in less accurate further processing, especially when outcomes from different accelerometers have to be compared. In the first summary derivation, the impact of the gravitational acceleration is intended to be removed by subtracting one from the final norm, while in the second summary derivation, the impact of the gravitational acceleration is intended to be removed by the high pass component of the bandpass filter. By examining the outcomes of the first summary derivation, left-overs of the gravitational impact are clearly visible, while in the second summary derivation, left-overs from the gravitational impact are not clearly visible which makes it more difficult to asses their quantity and form, making further correction challenging. Taking only the first summary derivation into consideration, further corrections can be made to ensure that the measurement does not reflect the influence of gravitation. By simply correcting the baseline to zero, the left-over impact of the gravitational acceleration can be reduced in the first derived summary, example in Figure 5.

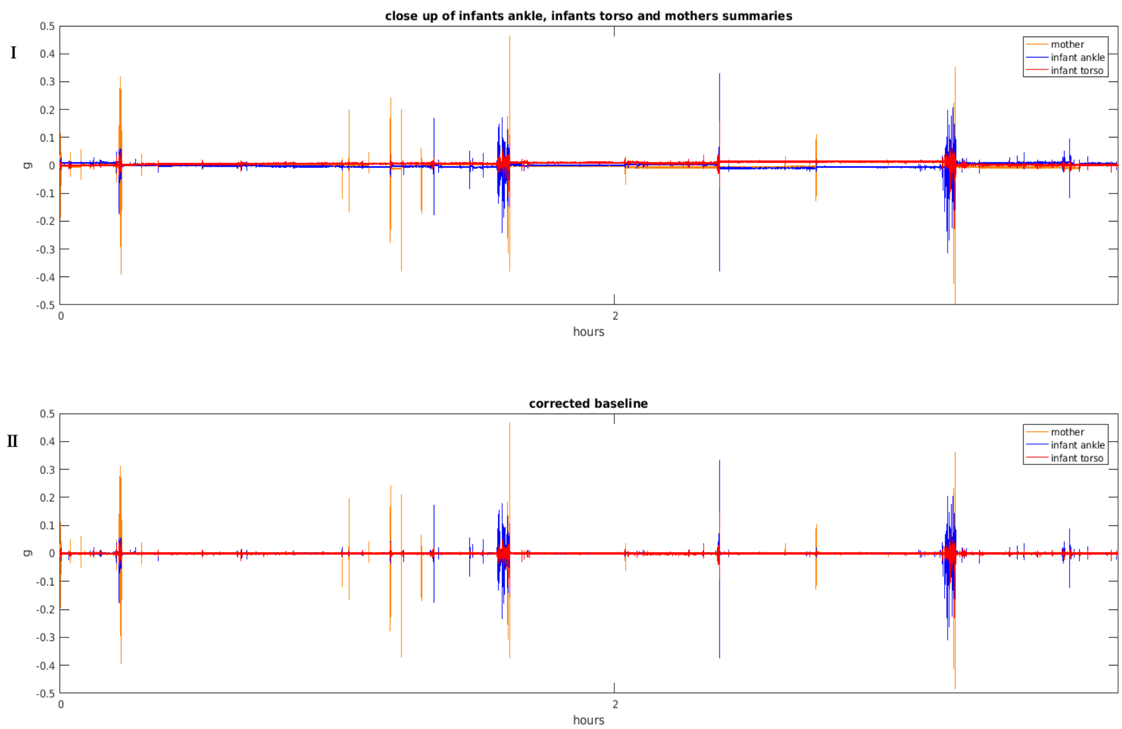


Figure 5: *An example of a close up of the first summary derivation for infant torso, infant ankle and maternal wrist accelerometer data, before (I) and after (II) the baseline correction.*

Baseline correction is implemented in Matlab based on a smoothing method with penalized least squares[4]. The method is an extension of the Whittakers method for smoothing, which works by minimizing the following sum:

$$S = \sum_i (y_i - z_i)^2 + \lambda \sum_i (z_i - 2z_{i-1} + z_{i-2})^2 \ , \tag{1}$$

where y is the input signal, z is the final smoothed signal and i goes through the data points. The first part of the sum ensures the best approximation of the input signal, while the second part represents the penalty for non-smoothness. In practice λ is set from $10^2 \leq \lambda \leq 10^9$ and its value depends on the input data and the desired final result. Since the goal of the baseline correction in the project was to keep all the amplitudes intact, but only correct the global baseline, λ is set to 10^9.
Reformatting the above into a linear system of equations, we get:

$$(I + \lambda D'D)z = y \ , \tag{2}$$

where I is the identity matrix and D is its differential matrix. The computational time and space can be optimized, using sparse matrices and Cholesky factorization. The resulted over-smoothed signal represents the baseline and is therefor subtracted from the measurement. This way, the amplitudes remain intact, but the baseline drifts and jumps are removed and the signal baseline is set to zero.

2.5 Caretakers contributing accelerations

The accelerometer is liable to pick up any acceleration caused by the subject moving, regardless if the subject is in PA or is being moved by another person. Infants at four months of age are completely dependent on the caretaker. Besides the basic tasks like feeding, bathing, dressing, etc., the infants at four months of age require a substantial amount of carrying, placing and cradling. This results in significant contributions of accelerations caused by the person caring for the infant[1][5][6]. In publication[5], the results also showed that the overall output differed significantly between the three differently placed accelerometers, when in fact recording the *same* activity, while the contributed accelerations could add up to more than a half of the detected activity. Since contributions differ significantly between the differently placed accelerometers, doubt raises whether a simple subtraction of the torso placed measurement from the ankle placed measurement will result in a valid and useful outcome and several more advanced and complicated approaches were designed and tested for this reason. In total, the following approaches were tested:

- **A.** Simple subtraction of measurements
- **B.** Subtraction of windowed intensities
- **C.** Correction based on windowed intensities
- **D.** Correction based on correlated windowed intensities
- **E.** Complete removal of periods, where caretakers contributing accelerations were assumed

In approach **A** the derived summary from the torso placed measurement was simply subtracted from derived summary of the ankle placed measurement. Example of a result from approach **A**, using the first summary derivation is shown in Figure 6, where it is apparent, that simple subtraction is not efficient, but rather amplifies the contributing accelerations. Example of the same result, but using the second summary derivation is shown in Figure 7, showing substantially different, but nevertheless still inefficient and inappropriate results, where analysis is required to asses whether the results from the two types of summary derivations are even comparable.

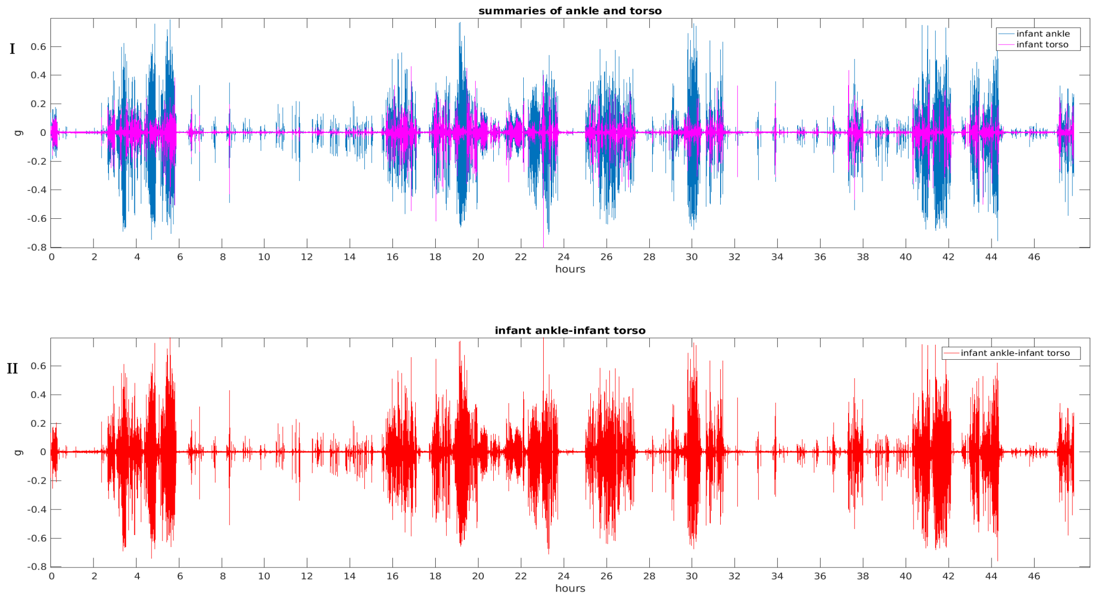


Figure 6: *A plot exhibiting the first summary derivations of the torso and ankle placed measurements (I) and the result of a simple subtraction of the torso placed measurement from the ankle placed measurement (II).*

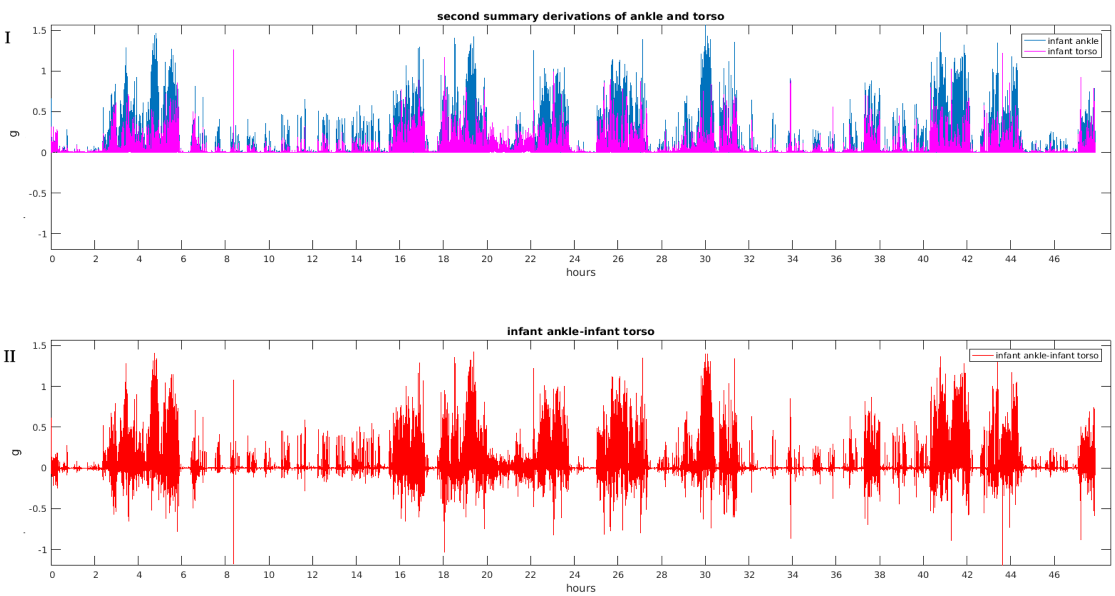


Figure 7: *A plot exhibiting the second summary derivations of the torso and ankle placed measurements (I) and the result of a simple subtraction of the torso placed measurement from the ankle placed measurement (II).*

As the measurements exhibit a substantial amount of similarity on a large scale, but seem to be too different point to point, the second (**B**) and third (**C**) approaches use an even more summarized measure, derived by calculating windowed absolute intensities. Specifying window length as k and measurement length as n, we get $\frac{n}{k}$ windows, for which the absolute intensity (AI) is calculated as following:

$$AI = \frac{1}{k} \sum_{i=1}^{k} |s_i|$$

where s is taken from the derived summary of the acceleration measurement.
In approach **B** the absolute intensities of the torso placed measurement are again simply subtracted from the absolute intensities of the ankle placed measurement. In approach **C**, the loss of resolution by further summarization is improved. The improvement is done by using the point to point ratio, between the windowed absolute intensities of the torso and ankle placed measurement, as a factor by which all the points in the corresponding window of the original summary derivation of the ankle placed measurement are decreased. For example, if the torso absolute intensity is half the ankle intensity, all the points in the corresponding window of the original summary derivation of the ankle placed measurement are decreased by a half of their size. The process is implemented in Matlab, where the window length was set to 2400 data points, which corresponds to one minute of measurement. Examples of a result in approach **B** and **C**, using the first original summary derivation are shown in Figure 8 and Figure 9, respectively. Examples of a result in approach **B** and **C**, using the second original summary derivation are shown in Figure 10 and Figure 11, respectively. Comparing with the approach **A**, the results from the two types of summary derivation appear less different in approaches **B** and **C**, which is examined with further analysis.

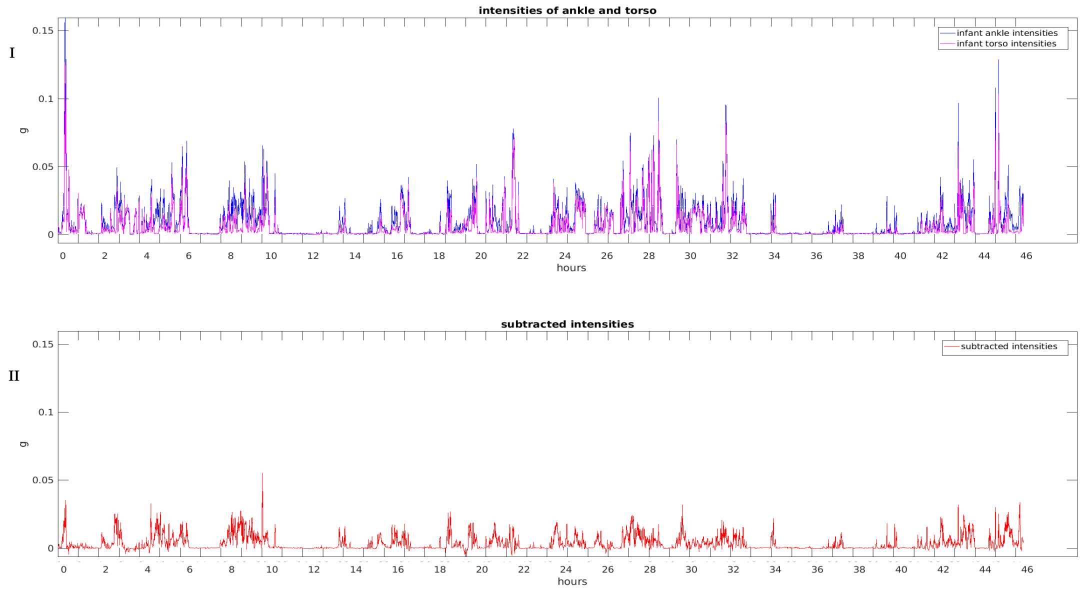


Figure 8: *An example of windowed absolute intensities obtained from the first summary derivations of torso and ankle placed measurements (I) and the result obtained by subtracting the windowed absolute intensities (II).*

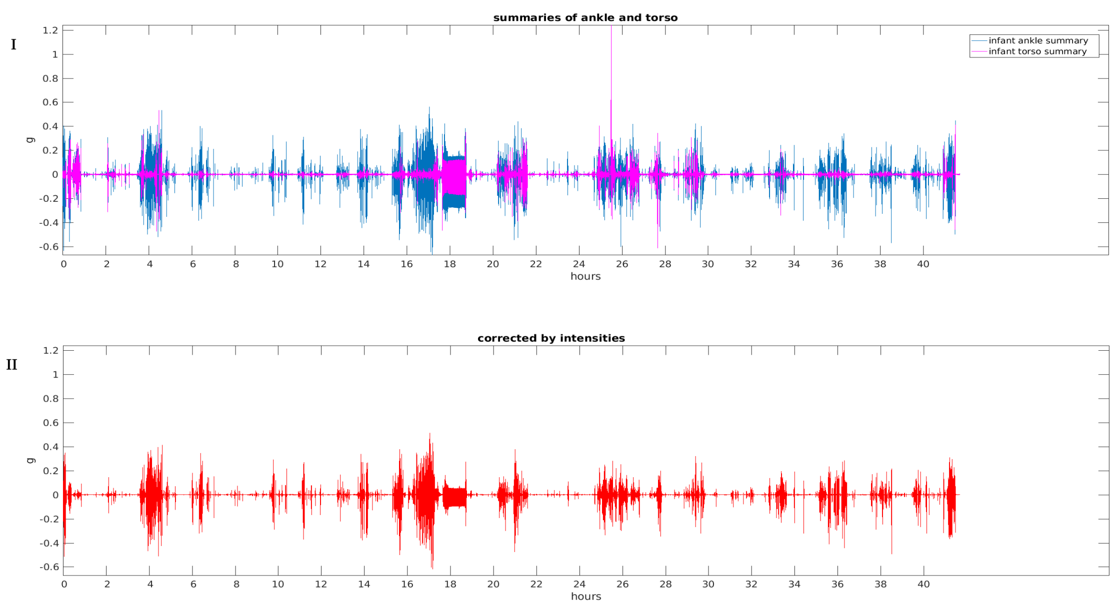


Figure 9: *A plot exhibiting the first summary derivations of the torso and ankle placed measurements (I) and the result (II) obtained by decreasing the accelerations in the first summary derivation of the ankle placed measurement by a factor equal to the ratio of the corresponding windowed absolute intensities.*

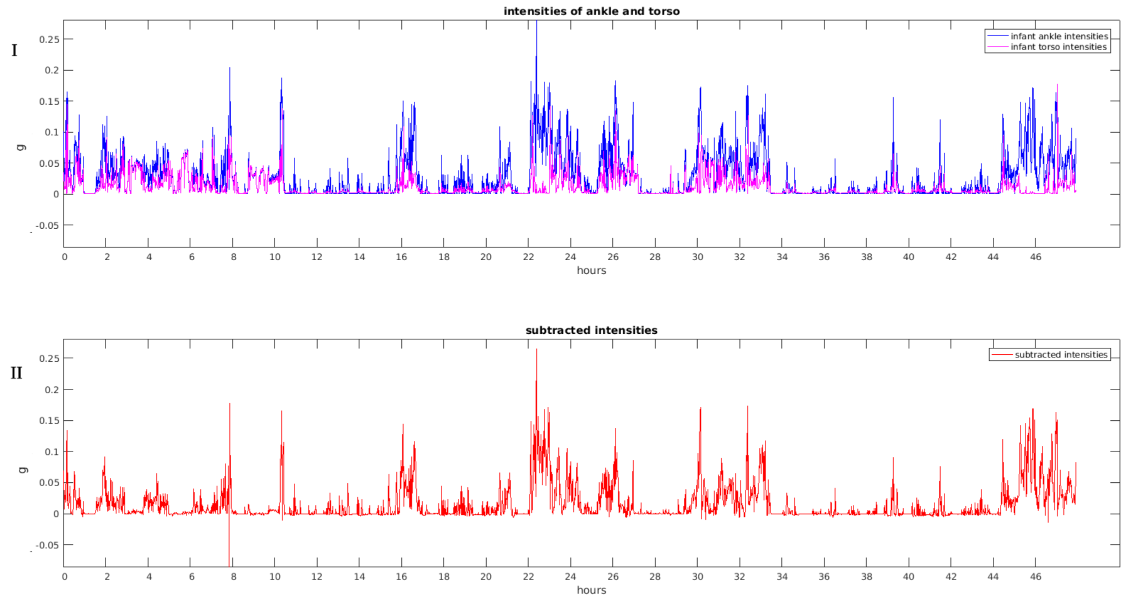


Figure 10: *An example of windowed absolute intensities obtained from the second summary derivations of torso and ankle placed measurements (I) and the result obtained by subtracting the windowed absolute intensities (II).*

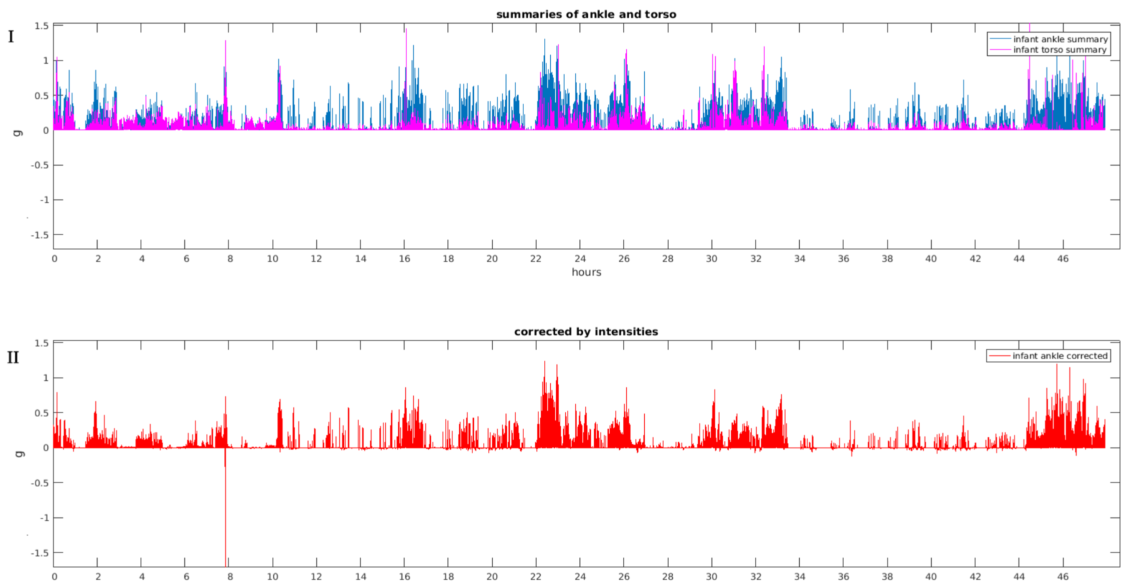


Figure 11: *A plot exhibiting the second summary derivations of the torso and ankle placed measurements (I) and the result (II) obtained by decreasing the accelerations in the second summary derivation of the ankle placed measurement by a factor equal to the ratio of the corresponding windowed absolute intensities.*

Although the accelerations on the ankle placed measurement are decreased in both approaches, the contributing accelerations are still clearly visible in both cases, while one can also observe negative absolute intensities due to the fact that the torso placed accelerometer can also record more intensive accelerations than the ankle placed one. Since it has been shown that the same activity performed by the caretaker with the infant is recorded differently by differently placed accelerometers, there should be a scaling factor involved when doing such subtractions or corrections. Obtaining such a scaling factor might be problematic, since it has also been shown that different activities result in different ratios between the differently placed accelerometers with high variability between the subjects [5].
Things get even more complicated if considering the fact that the two accelerometers will also pick up additional accelerations, mainly infants own accelerations which are unique for that specific body part, like for example accelerations due to crying, breathing, heart beats or kicking.
Without having a well-defined training dataset it is difficult to tell which of the remaining accelerations after approaches **B** and **C** are due to excessive detection of contributing accelerations on the ankle placed accelerometer or due to infants PA. Nevertheless, the approaches can be improved.
The concept of subtracting implies that the torso placed accelerometer will record accelerations equal or smaller then the ankle placed one, as well as that the degree of correction is dependent on the ratio of intensity instead of similarity. If similarity between the absolute intensities is obtained, it can be used as an approximation of the true scaling factor needed to accurately correct the ankle placed accelerometer.
In the approach **D**, an attempt is made to obtain signal similarities based on the similarity of windowed absolute intensities, using Pearsons correlation coefficient. The goal of the approach is to find similar patterns between the two measurements and then decrease the ankle placed measurement based on the degree of similarity. The idea behind this is that even though the two differently placed accelerometers might record the same activity different, there should be an underlying pattern in both, at least on a large enough window scale over the absolute intensities. For example some periods might exhibit similarity only in the global changes as shown in Figure 12, while others might be more similar even on the local scale as shown in Figure 13.

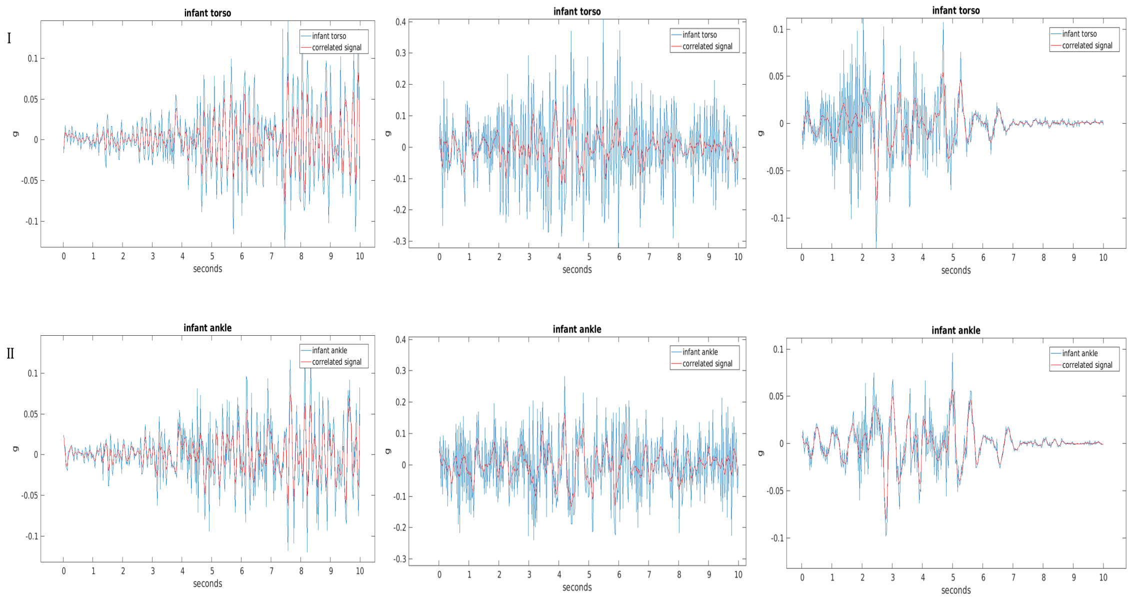


Figure 12: *A plot showing a few examples of similarities between the first summary derivations of the torso (I) and ankle (II) placed measurement on a global scale.*

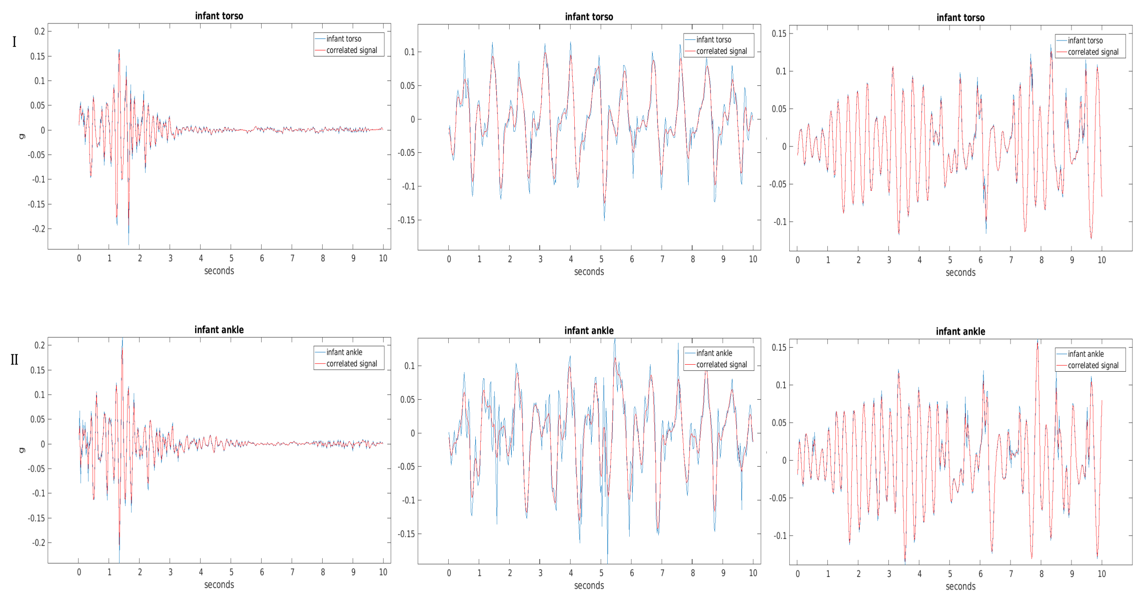


Figure 13: *A plot showing a few examples of more precise similarities between the first summary derivations of the torso (I) and ankle (II) placed measurement on a local scale.*

The main issue with previous approaches **A**, **B** and **C** are the local point to point differences between the two differently placed accelerometers recording the same activity. These differences are characterized by larger accelerations on one of the accelerometers, presence of previously mentioned additional accelerations or noise in one or both measurements or in a form a time lag, examples shown in Figure 14. Taking these differences into account, we would still like to determine if the two measurements in a given window are changing together due to being under the influence of the same activity, which is why calculating their covariance is of interest. Pearson correlation is obtained by dividing the covariance of the two variables by the product of their standard deviations and is a common correlation used for comparing signal similarities, especially in alignment[9]. The fact that it is invariant to separate changes in location and scale in the two variables being compared, gives it potential to expose the underlying similarities of the two differently placed accelerometers.

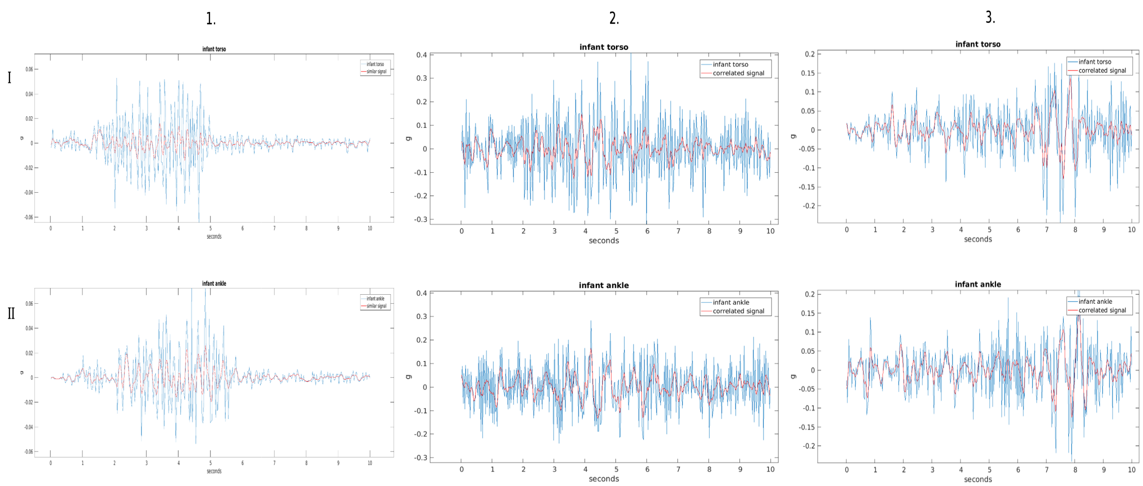


Figure 14: *First (1.) plot showing a slight time lag between the torso (I) and the ankle (II) placed measurement, second (2.) plot showing larger accelerations on the torso (I) placed accelerometer and the third (3.) plot showing the presence of additional accelerations and noise in both torso (I) and ankle (II) placed measurements.*

Nevertheless, large differences, previously mentioned additional accelerations and time lags can still influence the correlation coefficient. Even though Figure 8 and 9 exhibit similar patterns in the derived summaries of the torso and ankle placed measurement, the overall proportion of windows, where the correlation coefficient is large enough and significant, turns out to be very small. To get the desired results in approach **D**, further summarization is required in a form of windowed absolute intensities, as in approaches **B** and **C**.
Approach **D** is also implemented in Matlab. Absolute intensities are calculated for windows of 200 points, which corresponds to 5 seconds. Correlation coefficient is obtained with the build-in Matlab function *corr*, for windows of 24 windowed absolute

intensities, which corresponds to total 2 minutes, sliding with a step size 12, which corresponds to 1 minute. P-value is obtained using the permutation test with 10 repetitions. If p-value is insignificant, correlation coefficient is set to 0. While sliding, the first half will overlap with the previous window. Therefor, previous correlation coefficient is compared with the current and the biggest is used as a factor to decrease the first half of the corresponding window of the original derived summary of the ankle placed measurement, while the second half is decreased with a factor equal to the current correlation coefficient. The final result is the original summary derivation of the ankle placed measurement, where windowed accelerations are decreased by the factor equal to the correlation coefficient of windowed absolute intensities. Figure 15 shows an example of the first summary derivations of torso and ankle placed measurements and the corresponding result from approach **D**, along with the corresponding result from approach **C**, to enable comparison. Figure 16 shows an example of the second summary derivations of torso and ankle placed measurements and the corresponding result from approach **D**, along with the corresponding result from approach **C**, to enable comparison.

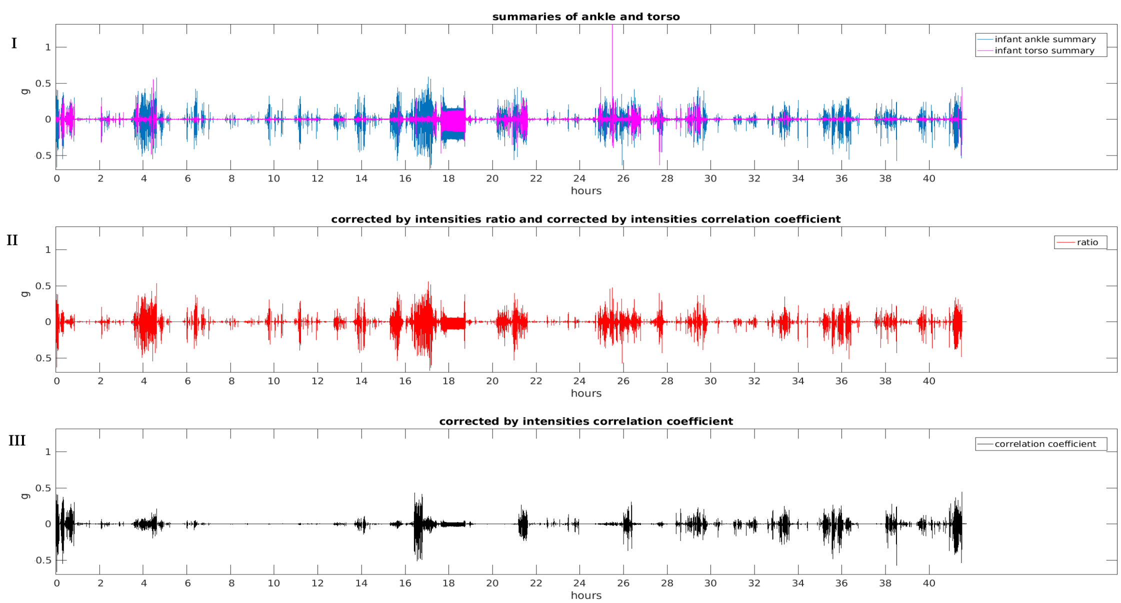


Figure 15: *A plot exhibiting the first summary derivations of the torso and ankle placed measurements (I) and the different results from approach **C** (II) and **D** (III). One can see substantially less left-overs from the contributing accelerations in the approach **D**.*

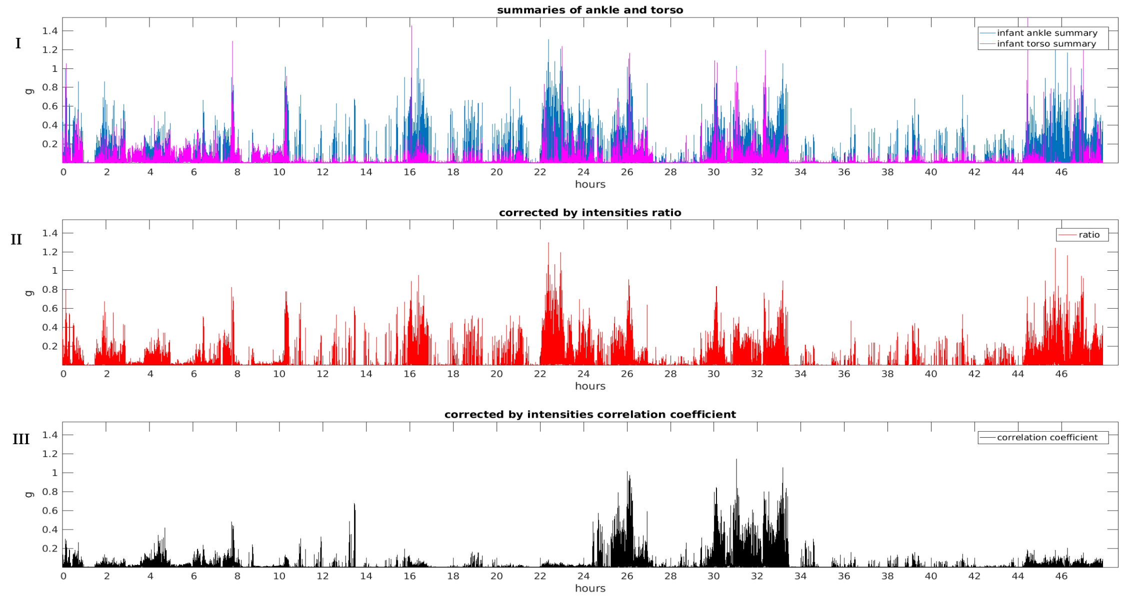


Figure 16: *A plot exhibiting the second summary derivations of the torso and ankle placed measurements (I) and the different results from approach **C** (II) and **D** (III). One can see substantially less left-overs from the contributing accelerations in the approach **D**.*

Although there are less visible left-overs of contributing accelerations after the approach **D**, there are still there and one would like to extract PA from a measurement that does not include any contributing accelerations. For that purpose, in approach *E*, periods where SD is increased in both, torso and ankle placed measurement, are extracted and removed, allowing only periods where large acceleration can only occur on the ankle placed measurement. The extracted periods approximate periods when the infant was being moved, by removing these periods, the following PA extraction should result in PA levels represented by the infants activity only. Periods when the infant was being moved are extracted similar as in non-wear detection, based on a threshold for SD of accelerations in periods of fifteen seconds. In other words, the periods when the SD of accelerations on both, torso and ankle placed measurements are above that threshold, the period is assumed to be a period when the infant was being moved. Different outcomes were observed based on several different values of the threshold. If the two summary derivations are significantly different and have a different amount of variance, then the threshold for increased SD due to being moved should be set accordingly for each type. Analysis will reveal how different are the two types of summary derivation and whether they have a different amount of variance.
Nevertheless, upon trial of different thresholds and the examination of the final total proportion of time the infant is detected as being moved, different outcomes were observed for the two types of summary derivation when using the same threshold. At the same time, observations showed that the final proportion of data removed due

to increased SD in both, torso and ankle placed measurements was quite high and dominant during the day, giving an impression as if only periods when the infant is sleeping remain. Therefor the threshold for SD of acceleration should be set carefully in order to best separate the periods when the infant is being moved and the periods when only the infant himself is active. Observations mentioned above were taken into consideration when doing further analysis, so that the most appropriate values for the threshold were set for each type of the summary derivation. Example of the obtained periods, when the infant was detected to be moved, for the first summary derivation, when setting the threshold value for SD of accelerations to 0.006 g, shown in Figure 17.

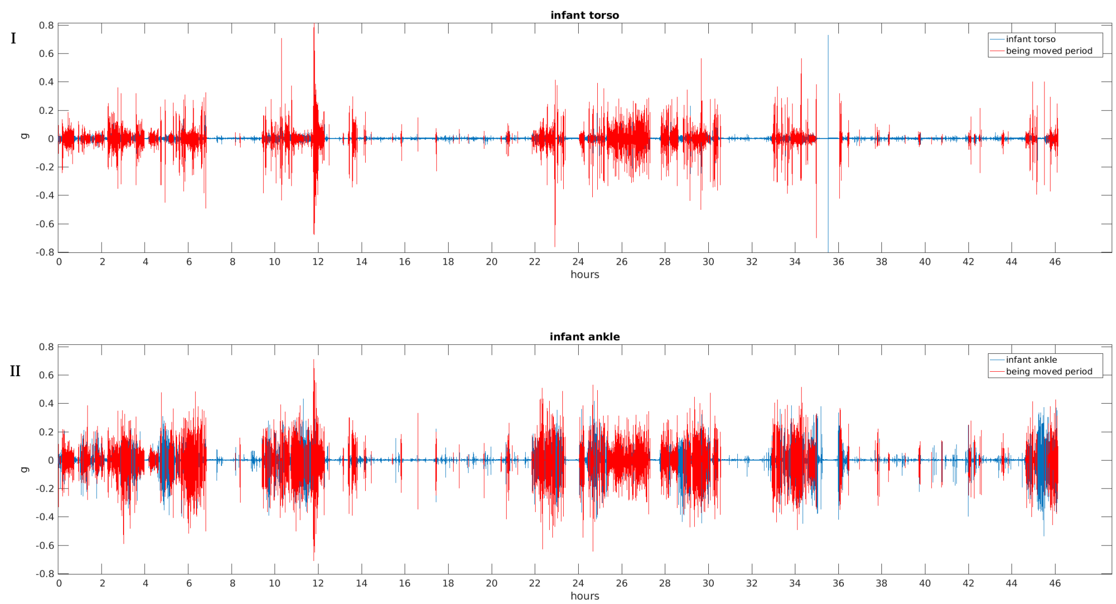


Figure 17: *Example of the first summary derivations of the torso (I) and ankle (II) placed measurements, where periods when the infant was being moved are highlighted in red.*

Each approach results in an ankle placed measurement, where the caretakers contributed accelerations were attempted to be removed. Those results are used for PA extraction, where further comparison and assessment of the different approaches can be made.

2.6 Physical activity extraction

PA was extracted from the corrected or remaining measurements, after removal of data points of non-wear time, summary derivation, correction for the gravitational component and the correction for caretakers contributing accelerations. In approaches where the result of the correction for caretakers contributing accelerations is in the form of the original summary, PA is extracted based on the increased SD in a windowed measurement, while in the approaches where the result of the correction for caretakers contributing accelerations is in a form of windowed absolute intensities, PA is extracted based on the increased intensities. Window size was set to 400 data points, which corresponds to 10 seconds and the step size was set to 40 data points, which corresponds to one second. Similar as in the extraction of periods when the infant was moved, the periods when the infant was active were extracted by setting the most appropriate threshold for each of the two types of summary derivation. Examples of periods when the infant was active, setting the threshold for SD to 0.005 g, based on the first summary derivation and caretakers contributions corrected with approach B, approach C, approach D or approach E shown in Figures 18, 19, 20 and 21, respectively.

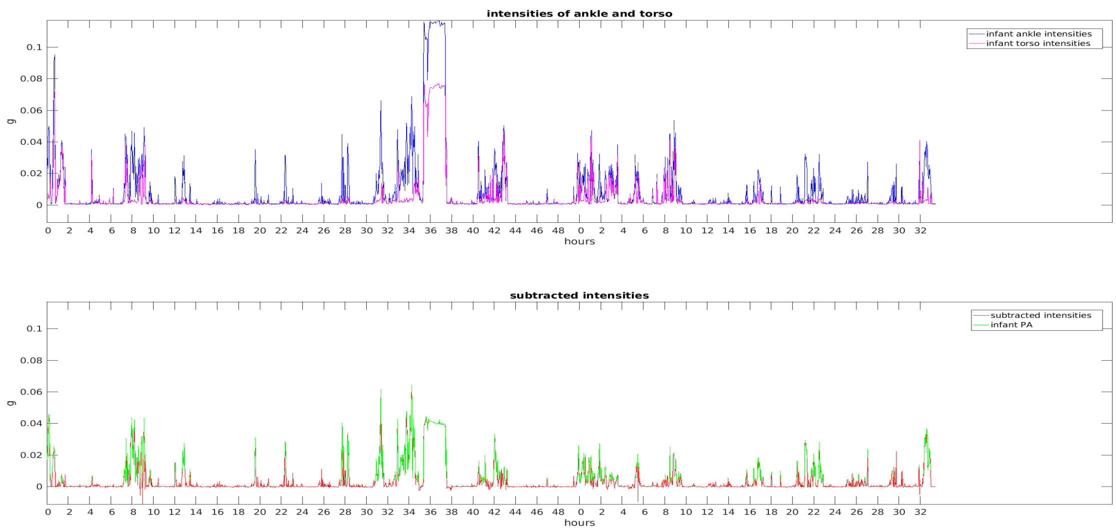


Figure 18: *PA extraction from the first summary derivation, based on approach **B**.*

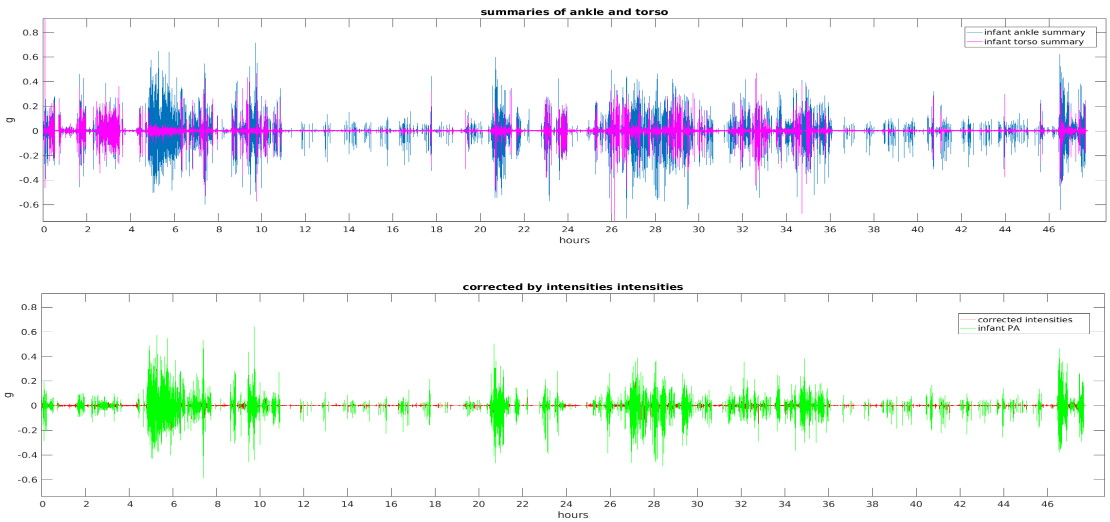


Figure 19: *PA extraction from the first summary derivation, based on approach **C**.*

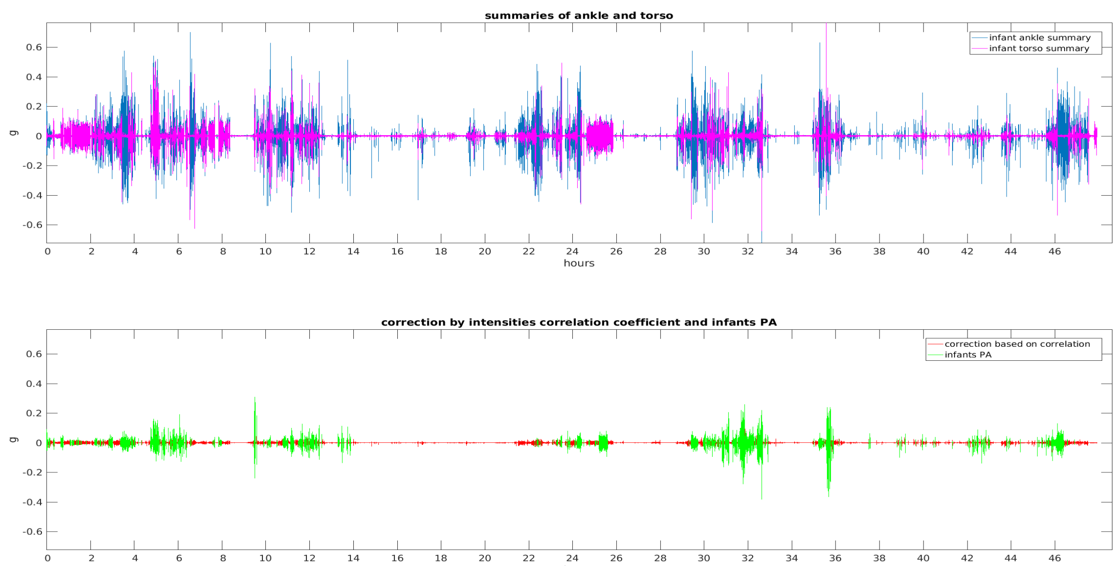


Figure 20: *PA extraction from the first summary derivation, based on approach **D**.*

After each approach, the extraction of PA reflects the consequences of the negative features of the approach. Different outcomes are compared with analysis in the next section.

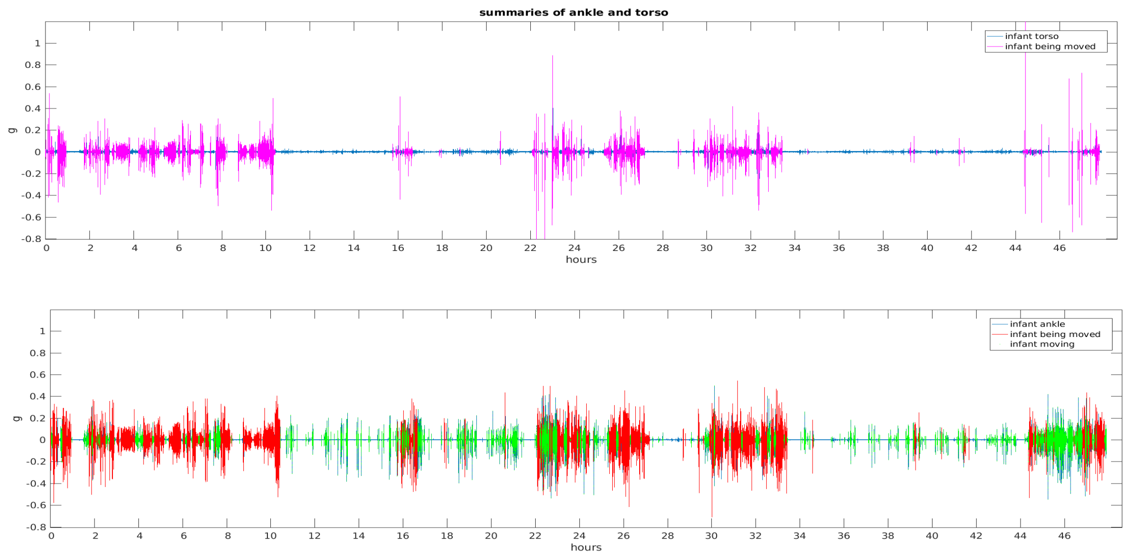


Figure 21: *PA extraction from the remaining first summary derivation, where all the periods when the infant was detected as being moved (red), were excluded (approach **E**).*

3 Analysis

The outcomes from different steps of accelerometer data processing were analyzed, compared and assessed, in order to obtain the most appropriate extraction of infants PA levels. First, the two different types of summary extraction were compared, based on their within and between subject variance and proportion of smaller accelerations on the torso placed measurement. Second, outcomes of different approaches for correction of caretakers contributing accelerations are compared for both types of summary derivation, based on the increase or decrease of the windowed SD and absolute intensities. Further more, in the approach **E**, the total final proportion of time the infant was detected as being moved was compared between the two types of summary derivation and for different thresholds for SD. For the most appropriate threshold, the values of the correlation coefficients, presenting similarity between torso and ankle, were analyzed between the time the infant was detected as being moved and the remaining time. Similar analysis was preformed for the proportion of time the infant spent in PA and the final proportions analyzed along with the proportions of time the infant was detected as being moved.

In the end, the results from the analysis were compared against the diary notations of infants sleeping and feeding habits.

3.1 Results

When analysing the difference between the two types of summary derivation and the amount of variance interfered, two windowed descriptive statistics are examined, SD and absolute intensity. Windowed descriptive statistics are caclulated for each of the 30 subjects, corresponding torso and ankle placed measurements, corresponding two types of summary derivation and the corresponding raw measurements of all three axis, x, y, and z. Additionaly, the proportion of smaller accelerations on the torso placed measurement is extracted and compared bewtween the two types of summary derivation. For all descriptive statistics, mean and variance was compared between the raw measurements and the two types of summary derivation, as well as between the differently placed accelerometers. Comparison was done with a MANJKA test, results in Table 1. Boxplots for SD, absolute intenisity and proportion of smaller acceleration on the torso are shown in Figure 22, 23 and 24 respectively.

MANJKA 22, 23, 24, tabela 1

Boxplots and statistical analyses showed that the two types of summary derivation produce a different scale for the acceleration size and that the MANJKA summary derivation has a higher whitin and between subject variation, as well as between the differently placed monitors. While this is a good example why caution is required when summarizing accelerometer data and choosing appropriate thresholds, the source of variation should be assessed more precisely. For this reason, two types of summary derivation are analyzed further, by comparing and analysing the outcomes of different approaches correcting the caretakers contributing accelerations. In Figure 25, the boxplot shows the overall increase or decrease of the descriptive statistics after the different approaches. Differences between the two types of summary derivation are assessed with a T-test and shown in Table 2.

MANJKA 25, tabela 2

From the total proportions of increased or decreased descriptive statistics, it is clear that approach **A** is inappropriate, since both descriptive statistics are increased in both types of summary derivation, while approaches **B**, **C** and **D** have more potential to be efficient since in all cases the descriptive statistics decrease in both types of summary derivation. Approach **E** is not included in the analysis, since the principal is different. In approach **E**, the periods when the infant is being moved are not attempted to be corrected, but are simply removed. If one would like to strickly analyze infants activity patterns only, approach **E** should be the most appropriate, since the caretaker will not only confound the amount of accelerations, but also the overall movement of the infant, for example by stimulation, restriction by holding, reduction due to diversion of attention etc. Ideally, the approach for correcting caretakers contributing accelerations should only correct periods when the infant is being moved. Two types of summary derivation and different approaches can be analyzed further to asses which case gives the best results. When examining the outcome of approach **E**, several thresholds for SD are set and different proportions of the total time detected as infant being moved are obtained and compared between the two types of summary derivation. Spearmans rank correlation coefficient is highest when the threshold for the first summary derivation is set to MANJKA and the threshold for the second summary derivation set to MANJKA. Table 3 shows the final results of the total proportion of time detected as infant being moved for the two types of summary derivation. MANKA tabela 3 Having extracted 15 seconds periods and separated them into two classes, infant being moved and infant not being moved, the descriptive statistics of the two types of summary derivation can be examined further. In Figures 26, 27 and 28 the boxplots show the differences between the grouped periods for the ankle placed measurement for the two types of summary derivation.

MANJKA 26, 27, 28 in comment

Pearsons correlation coefficient can be examined as an additional descriptive statistic representing the similarity between the torso and ankle placed measurement and compared between the grouped periods. In Figure 29, boxplots show Pearsons correlation coefficient of the windowed absolute intensities for the grouped periods, for all 30 subjects and the two types of summary derivation. Differences between the groups are assesed with a T-test and shown in Table 4.

MANKA 29 in tabela 4

Based on the analysis and results above, MANKA summary derivation is more appropriate to be used futher. In further analysis, the best approach must be selected for the estimation of infants activity. The proportion of time the infant was detected as active differed between the various approaches. One could already expect that extracting and analyzing PA based on the approach A will be meaningless, as the majority of accelerations present are still due to caretakers contributing accelerations. In fact, based on approach A and using the first summary derivation, the comparison between the infants active and being moved time, resulted in Spearmans rank correlation coefficient equal to 0.84 with p-value 0, example shown in Figure 30.

This makes sense, as infants PA time and being moved time is extracted with the same procedure, using a slightly different SD cutpoint. Considering this, along with the observation, that subtraction does not remove contributing accelerations, but in fact enhances them, it is not surprising these proportions end up being very similar. With approaches **B** and **C** better results can be expected. PA extraction, using the first summary derivation and based on approach **B**, resulted in infant being in PA on an average of 34.3% of his 'own time', with min 23.0%, max 45.0% and SD 5.4%, while based on approach **C**, infant was in PA on an average 32.5% of his 'own time', with min 21.9%, max 42.0% and SD 4.8%.

These numbers are similar, although one would expect them to differ more, since first approach extracts PA from subtracted absolute intensities that can be negative. One explanation could be that these errors even out and by averaging over the subjects, the final outcome will be similar, example of a boxplot of the two extracted PA proportions over all subjects shown in Figure 31.

When examining the results from approach **C** along with the proportion of time the

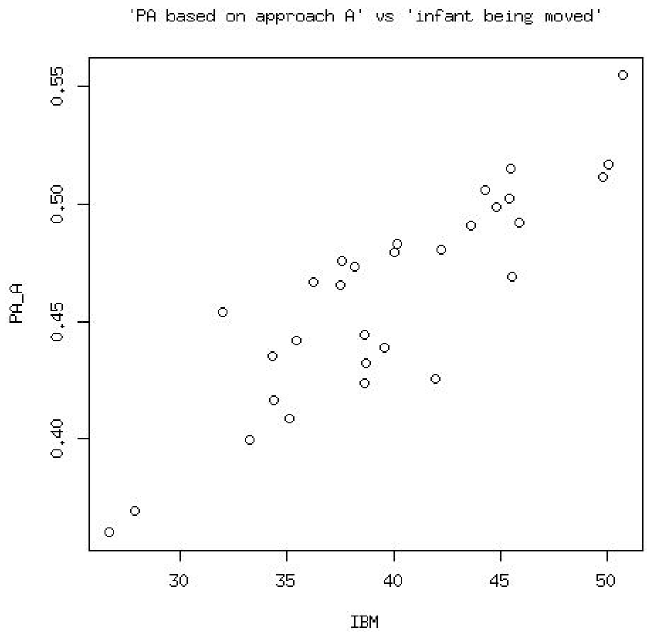


Figure 22: *Comparing the proportion of infants PA time and being moved time, after approach **A** and using the first summary derivation.*

infant was being moved, plots still exhibit slight correlation between the two variables, with exception of a few outliers, example shown in Figure 32.
Over all subjects, the proportion of time in PA after approach **B** and the proportion of time the infant was being moved produced a Spearmans rank correlation coefficient of 0.48 with p-value 0.0072, while with the proportion of time in PA after approach **C** the coefficient was 0.64 with p-value *2e-04*. One could speculate that such correlation is due to the left overs of the contributing accelerations, although there is a chance that caretakers influence infants own PA by interaction. Moving on to approach **D**, PA extraction resulted in an average of 25.5% of infants 'own time', with min 12.3%, max 47.6% and SD 0.09%. Spearmans rank correlation coefficient for the comparison of the proportion of time in PA after approach **D** and the proportion of time the infant was being moved resulted in 0.41 with a p-value 0.0236. Scatterplot of proportion of time in PA vs. proportion of time being moved shown in Figure 33.

Although there is less significant correlation between infants activity and being moved time then in previous approaches, there is still a substantial amount, but again with uncertainty, whether this due to the contributing accelerations, same procedure of extraction, or caretakers interference. So far, all the extracted PA variables were liable to be confounded by the contributing accelerations. With the last approach, one would expect to have no correlation with the proportion of the time infant was moved,

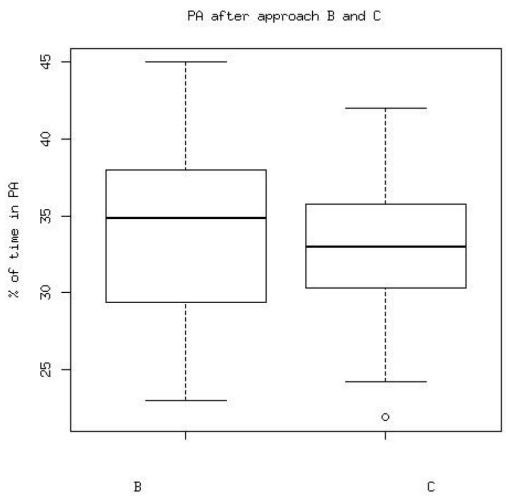


Figure 23: *Comparing the proportion of time in PA between approaches **B** and **C**, over all subjects, using the first summary derivation.*

since it had all been removed and the final PA variable should not be confounded. The resulting proportion of time the infant was in PA, based on approach **E** and using the first summary derivation, was on average 19.4% with minimum 12.8%, maximum 26.0% and SD 3.2%. When correlating the proportion of time in PA with the proportion of time being moved, Spearmans rank correlation coefficient results in -0.42 with p-value 0.0218. The sign and quantity of correlation imply that there is a negative relationship between the two. Scatterplot of the proportion of time in PA vs. proportion of time being moved in Figure 34. Considering only the methodological reasons for this implication, one could speculate that by removing all the parts where the infant was being moved, in a short time period of 48 hours, will result in very little measurement left for the infants PA to be detected. Keeping in mind the infants at 4 month old age are very dependent on the caretaker, especially while awake, one can also speculate, the majority of measurement left after approach **E** will belong to the time when infant was sleeping. Such interference could leave consequences, even if the final PA variable is normalized with the amount of time left after the approach. More can be explored and validated with the help of diaries, kept by the infants mothers. This is discussed in the next subsection, where the rest of the extracted variables are also analyzed.

3.2 Diary validation

During the free living experiment, the mothers were instructed to keep a diary of the infants feeding and sleeping habits, along with other valuable information regarding the experiment, like for example removal and reattachment of the accelerometer. All

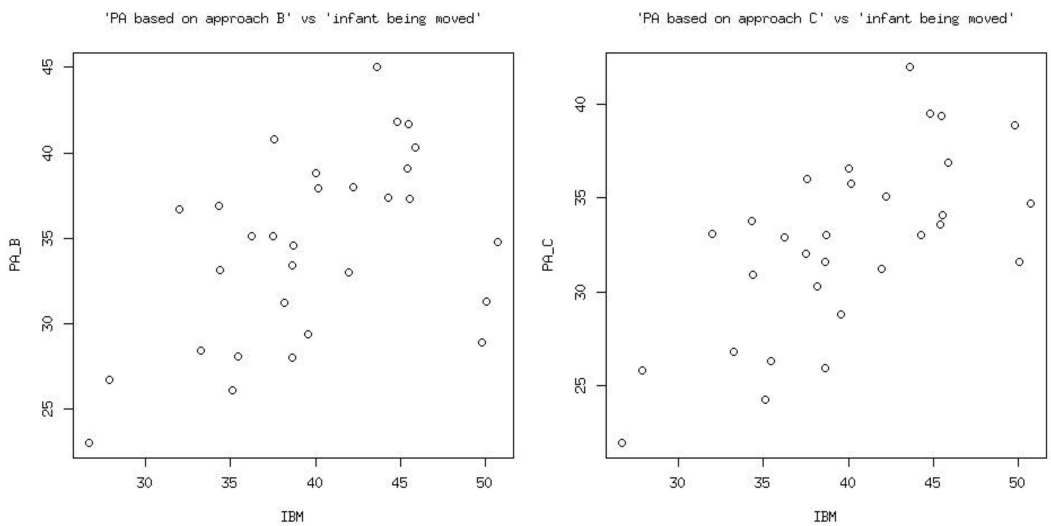


Figure 24: *Comparing the proportion of infants PA time and being moved time, after approach **C** and using the first summary derivation.*

subjects had the diary data available, except one, where the diary was missing. The diary consisted of printed forms, example in Supplements. Besides a few exceptions, the mothers started keeping diary notations on the second day, from midnight on. This already presents a drawback, since the accelerometer data was recorded only for 48 hours from the morning of the first day on, meaning that out of those 48 hours, approximately 15 hours will not have corresponding diary notations.
Since the diaries were filled by handwriting, the notations inside had to be digitized, to enable automatic comparison and validation. Although one could attempt to achieve this automatically by document scanning and image analysis, such approach would be too complicated and time-consuming for the needs of this project, where only 30 documents had to processed. Therefor these documents were examined manually, which was nevertheless still very time consuming and error prone. For several reasons, a substantial amount of error was also introduced by the mothers keeping the notations. Mainly this was due to rounding up the noted time, having trouble keeping up with notations and then not being able to recall the time of certain occurrences.
First, the diary forms enabled notation of accelerometer removal and reattachment, where the mothers had to note which of the accelerometers is being taken off, corresponding comments and the absolute time of removal and reattachment. Frequently, the mothers commented that the accelerometer was forgotten to be put back on after removal and the times noted are therefor approximate. Secondly, the diary forms included a schedule over 24 hours, over a week, where the mothers were instructed to note the infants sleeping time with a stroke. As one can see in the Supplements, the sleeping schedule is not so big, meaning that the space for one hour is very small. Consequently, it was difficult for the mothers to keep accurate and consistent nota-

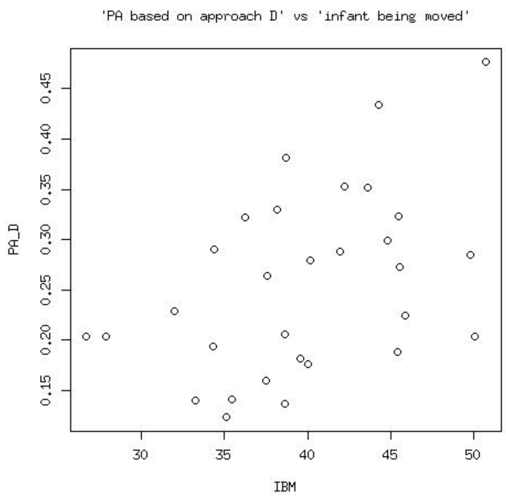


Figure 25: *Comparing the proportion of time in PA after approach **D** and the proportion of time the infant was being moved, over all subjects, using the first summary derivation.*

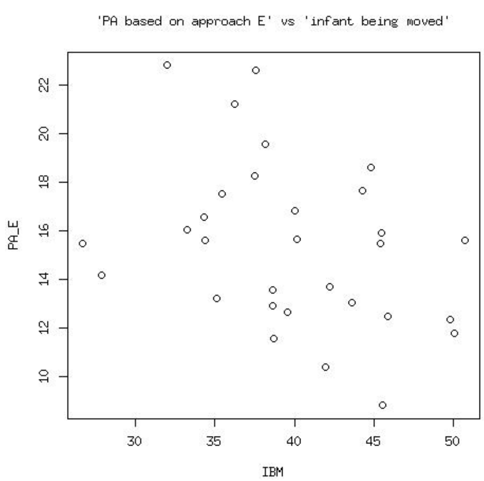


Figure 26: *Relationship between the proportion of infants PA after approach **E** and proportion of being moved time.*

tions of infants sleeping time. The noted times became even less accurate, when the mothers forgot to note regularly and had to therefor recall the approximate times of sleeping. For the validation and comparison of data analysis, absolute timestamps were needed and had to be therefor created manually, by examining these schedules, which introduced even more error. The final timestamps were therefor liable to be very approximate and error prone and one should begin to question whether comparison and validation against such timestamps is useful and valid itself. Last, mothers were instructed to keep a diary of infants feeding time, by noting down the begin time and duration of feeding, along with a few other comments, not relevant for this project. Feeding notations had to be transformed into begin and end timestamps, to enable validation and comparison. Example of the final data table, created manually based on a diary in Table 1.

feeding start	feeding finish	sleeping start	sleeping finish	torso accelerometer detached	torso accelerometer reattached
2009-02-10 08:20:00	2009-02-10 08:50:00	2009-02-10 00:00:00	2009-02-10 08:10:00	2009-02-09 11:30:00	2009-02-09 16:00:00
2009-02-10 09:30:00	2009-02-10 10:00:00	2009-02-10 13:00:00	2009-02-10 13:40:00	2009-02-09 18:30:00	2009-02-09 20:00:00
2009-02-10 10:00:00	2009-02-10 11:00:00	2009-02-10 15:00:00	2009-02-10 15:25:00	2009-02-10 21:10:00	2009-02-11 08:15:00
2009-02-10 14:15:00	2009-02-10 15:00:00	2009-02-10 19:00:00	2009-02-10 19:40:00		
2009-02-10 15:50:00	2009-02-10 16:20:00	2009-02-10 22:20:00	2009-02-11 08:25:00		
2009-02-10 17:30:00	2009-02-10 17:45:00	2009-02-11 10:30:00	2009-02-11 11:40:00		
2009-02-10 20:00:00	2009-02-10 20:30:00	2009-02-11 13:25:00	2009-02-11 14:00:00		
2009-02-10 21:00:00	2009-02-10 21:15:00	2009-02-11 19:30:00	2009-02-11 20:05:00		
2009-02-11 08:20:00	2009-02-11 09:30:00	2009-02-11 22:00:00	2009-02-12 08:25:00		
2009-02-11 11:30:00	2009-02-11 11:45:00				
2009-02-11 14:15:00	2009-02-11 15:00:00				
2009-02-11 15:00:00	2009-02-11 16:00:00				
2009-02-11 16:50:00	2009-02-11 17:15:00				
2009-02-11 17:30:00	2009-02-11 17:45:00				
2009-02-11 19:15:00	2009-02-11 19:35:00				
2009-02-11 20:30:00	2009-02-11 21:00:00				
2009-02-11 21:15:00	2009-02-11 21:30:00				

Table 1: *Example of a data table, created manually based on a diary kept by the infants mother.*

Overall, the handwritten diaries were hard to examine, due to unclear handwriting and sloppy notes which often did not make sense. It became likely that the diaries will not provide the desired means for validation, especially if considering the amount of error along with the frequency of feeding and sleeping occurrences. Nevertheless, the diary timestamps were compared against the timestamps obtained through data analysis in an attempt to extract any kind of validating information.
First, timestamps obtained through automatic non-wear time detection were compared to the timestamps generated based on the diaries. The comparison was implemented in Python, with the help of modules *pandas*, *datetime* and *dateutil*. Even though the exact time of the beginning and end of non-wear occurrences differed between the timestamps for an average of one hour, all the major non-wear occurrences were detected, with a few exceptions of either very short non-wear occurrences or occurrences where the accelerometer was noted as not being worn, but the measurement clearly showed movement. Based on the visual examination of plots with no-wear time marked, the timestamp differences were due to the errors in the diary based timestamps and not in the data analysis. Second, the timestamps obtained through detection of infant being moved and the timestamps obtained through detection of infants PA were compared to the sleeping and feeding blocks noted in the diary. Ideally one would expect to have *infant being moved* detected around the begin and end of sleeping blocks and all through out from begin to end of a feeding block, while there should be less *infant being moved* detected, while the infant is sleeping, when there should also be substantially less infants PA. Considering the amount of error introduced with the diaries and the frequency of sleeping and feeding occurrences, it would be uninformative to compare the exact timestamps and their differences, instead, for all detected timestamps of *infant being moved*, proportions of time were calculated regarding into which

diary block the timestamps fell. Altogether, nine blocks were defined. A block of time where the infant was sleeping and feeding, sleeping only, feeding only, close/around of a sleeping and feeding block, close/around to sleeping only block, close/around to feeding only block, inside of a sleeping block, but also being close/around a feeding block, inside of a feeding block, but also being close/around a sleeping block and the final block being none of the above, meaning infants free awake time. Final proportions overall subject in Table 2.

overall subjects	inside of a sleeping and feeding block	inside of a sleeping block only	inside of a feeding block only	close to start or end of a sleeping and feeding block	inside of a sleeping block but also close to the start or end of a feeding block	inside of a feeding block but also close to the start or end of a sleeping block	close to start or end of a sleeping block only	close to start or end of a feeding block only	not in or near feeding or sleeping block
mean	0.69%	38.10%	3.49%	2.88%	2.79%	0.65%	16.45%	5.52%	29.39%
min	0%	26.40%	0%	0%	0%	0%	8.41%	0.27%	16.37%
max	4.77%	59.02%	23.87%	6.62%	11.79%	3.36%	27.81%	16.64%	45.61%
SD	1.18%	9.51%	6.98%	1.70%	2.98%	0.85%	5.00%	3.56%	9.74%

Table 2: *Table of timestamp proportions falling in certain diary blocks.*

The biggest proportions are represented by the sleeping block only and infants free awake time, although the SD is very high with both. On average, SD is very high for all the defined blocks and the span between minimum and maximum is large, showing a substantial amount of variability between the subjects. In figures 24 and 25, examples of plots where the measurement is noted with *infant being moved* blocks, sleeping and feeding blocks and night time, show the variability and the frequency of different occurrences, resulting in less informative validation. For more accurate results, the amount of day and night time should be taken into account as well, since the accelerometer data lacks 15 hours of diary data and the rest of the 33 hours will have two nights and only one day, which results in more *sleeping* time.

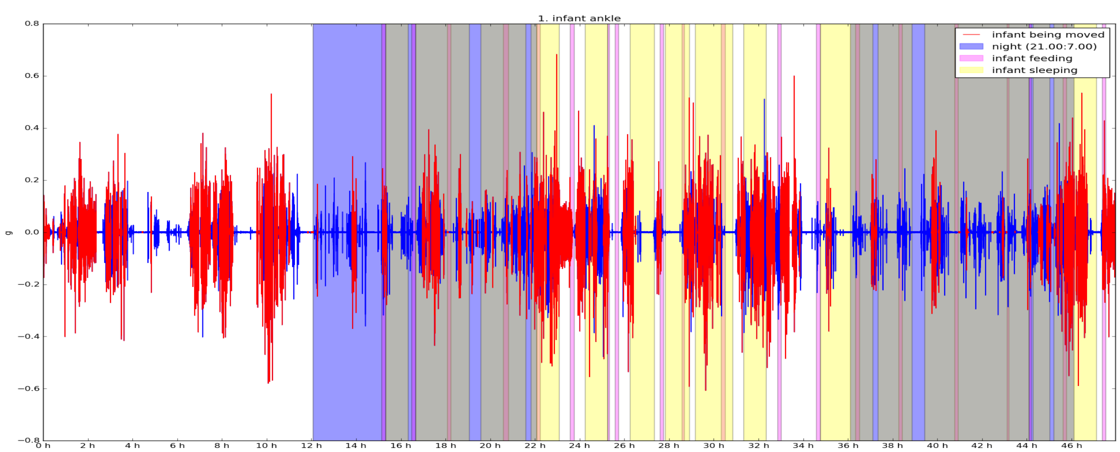


Figure 27: *The sleeping and feeding occurs in short blocks all through the experiment, night time is less expressed.*

Evidently, the diaries are not precise enough to validate the detection and correction of the contributing accelerations. Nevertheless, the extracted proportion of PA can

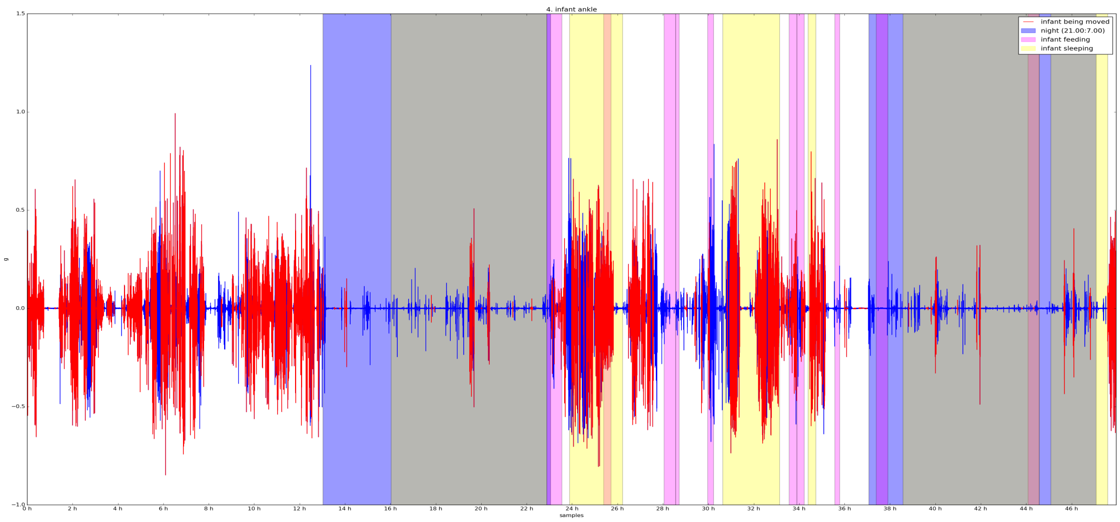


Figure 28: *The sleeping and feeding occurs in larger blocks, night time is more expressed with clearly less infant being moved blocks.*

be compared against the sleeping and awake blocks, in order to compare the amount of PA during sleeping and during awake time. Table 3 presents the proportion of time the extracted PA occurred while infant awake time.

	approach C	approach D	approach E
mean	48.12%	45.87%	35.48%
min	30.60%	23.98%	14.21%
max	61.51%	61.13%	59.02%
SD	10.83%	09.02%	12.71%

Table 3: *Proportions of PA occurring while infant awake, after different approaches.*

In all approaches, the average proportion of PA occurring while infant sleeping is larger then expected, although the SD of the proportions is again very high, as is the span between the minimum and maximum and most importantly, the outcomes might not be accurate, since as previously mentioned, normalization with the total sleeping and awake time should had been done. Nevertheless, it is an approximation of the differences between the approaches. After approach **E** the average proportion of PA occurring during infant awake time is the smallest, implying as if the infant is more active during sleep. Considering previous observations regarding approach **E**, there is a chance that by removing all the blocks of *infant being moved*, the extraction of PA becomes too limited on the time the infant was sleeping, example in Figure 26.
Overall, the validation against the diaries did not provide the desired and planed

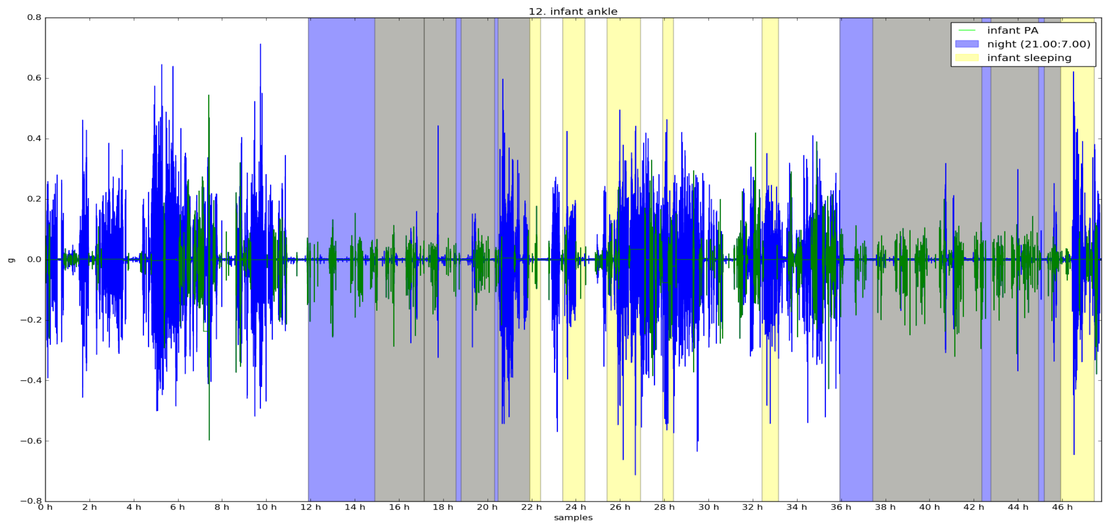


Figure 29: *Example of the extracted PA along with the diary noted sleep and night time according to the absolute timestamp.*

validation due to the amount of error present in the diaries and introduced with digitization as well as due to fact that the accelerometer measurement and diary notations overlapped only for two nights and one day, which is not sufficient and biased to *sleeping* time. Another issue is the high variability between the subjects, which was also observed in the previous steps of analysis. This overall high variability present between the subjects, between the activities and between the accelerometers might be too high for the size of the dataset. For example, the diary noted, sleeping and feeding proportions had high variability between the subjects, example in Table 4, raising doubt if validation over 29 subjects for 33 hours is possible.

over all subjects	sleeping time	feeding time
mean	63.00%	9.63%
min	38.99%	3.30%
max	81.60%	27.01%
SD	9.39%	6.01%

Table 4: *Proportion of sleeping and feeding time overall subjects with a diary available.*

One could also question whether the detection of contributing accelerations is possible with the size of the dataset and the amount of variability. This is discussed in the next section.

4 Closure

4.1 Discussion

None of the approaches resulted in a validated PA variable and now the question is, how feasible it is to estimate infants PA based on 30 subjects, using accelerometers in 48 hours. Table 5 gives examples of variability present in a dataset of 30 subjects.

	mean over all ankle summary	mean SD of infant being moved blocks	mean of the proportion of smaller torso placed measurement
mean	2.0993e-12 g	0.013 g	52.9%
min	-0.313 g	0.0103 g	47.8%
max	0.355 g	0.183 g	62.3%
SD	0.011 g	0.002 g	0.02%

Table 5: *Examples of variability in the dataset of 30 subjects.*

With such high variability, one should consider the statistical power/sample size of the analysis, which will nevertheless, still have to be better than the approaches in this project. Even if having an appropriately sized dataset with a reasonable chance of finding the underlying similarities between torso and ankle placed measurements, there are still issues present. For example, in approach **E**, one would need to estimate for how long would one have to measure infants PA to avoid interfering with the final results by extracting PA mainly during when infant is sleeping, if that is even possible. In approach **D**, a better method for assessing similarity is necessary, while it would also be necessary to consider the amount of similarity when the infant is not being moved by the caretaker. Here, it might be useful to examine, whether the two signals were more correlated within the apparent *infant being moved* blocks, compared to the rest of the measurement. Unfortunately, for this project, this analysis is yet to be performed as the necessary time exceeds the one intended for this project.

4.2 Conclusions

The torso and ankle placed measurements exhibit a substantial amount of similarity on a large scale, which implies contributing accelerations due to infant being moved by the caretaker. The overall presence of similarity and the amount of blocks with highly increased SD of the torso placed measurement, correspond to the previous reports regarding confounding accelerations due to infants caretaker [1][5][6]. High variability present between the subjects and their characteristics is also observed as in previous reports. To enable a valid extraction of infants PA, the contributing accelerations need to be removed. Based on the approaches developed and explored in this project, one has to consider:

- There is a substantial amount of difference between the torso and ankle placed measurements on a local scale, therefor a good enough summary of the measurement has to be derived,
- The torso placed measurement is not necessary smaller then the ankle placed one, so any kind of subtracting might result in impaired further analysis,
- Extracting signal similarities could be a potentially good approach to correct contributing accelerations,
- Removing all the apparent blocks of *infant being moved* might interfere with the extraction of PA,
- With high overall variability, sample size must be considered
- To obtain appropriate and valid means of validation.

References

[1] Worobey J, Vetrini NR, Rozo EM (2009) Mechanical measurement of infant activity: A cautionary note. *Infant Behav Dev* 32(2):167-72.

[2] van Hees VT, Renstrom F, Wright A, Gradmark A, Catt M, et al (2011) Estimation of Daily Energy Expenditure in Pregnant and Non-Pregnant Women Using a Wrist-Worn Tri-Axial Accelerometer. PLoS ONE 6(7): e22922. doi:10.1371/journal.pone.0022922

[3] van Hees VT, Gorzelniak L, Dean Leon EC, Eder M, Pias M, et al. (2013) Separating Movement and Gravity Components in an Acceleration Signal and Implications for the Assessment of Human Daily Physical Activity. PLoS ONE 8(4): e61691. doi:10.1371/journal.pone.0061691

[4] P. H. C. Eilers (2003) A Perfect Smoother. *Anal. Chem.* 2003, 75, 3631-3636

[5] Spencer C, Taylor R, Gray A, Dale K, Taylor B. (2012) Use of accelerometer to measure physical activity in 6 month old infants. *Australia New Zealand Obesity Society Conference* (ANZOS) 2012: *For our children's children*. Auckland, New Zealand.

[6] Christine Moir (2014) Physical activity in infancy: assessment of an intervention to increase physical activity in infants.
A thesis submitted for the degree of Doctor of Philosophy at the University of Otago, Dunedin, New Zealand

[7] Zhang S, Murray P, Zillmer R, Eston RG, Catt M, Rowlands AV (2012) Activity classification using the GENEA: optimum sampling frequency and number of axes. *Med Sci Sports Exerc.*;44(11):2228-34. doi: 10.1249/MSS.0b013e31825e19fd.

[8] Phan DH, Bonnet S, Guillemaud R, Castelli E, Pham Thi NY (2008) Estimation of respiratory waveform and heart rate using an accelerometer. Conf Proc IEEE Eng Med Biol Soc 2008: 4916-4919.

[9] Di Lena P, Margara L (2010) Optimal global alignment of signals by maximization of Pearson correlation. *Information Processing Letters 110 (2010)*: 679-686

[10] https://en.wikipedia.org/wiki/Pearson_product-moment_correlation_coefficient#Using_a_permutation_test

[11] Perlin M, Bustamante DM (2014) A Robust Quantitative Comparison Criterion of Two Signals based on the Sobolev Norm of Their Difference.
arXiv:1412.6977 [physics.flu-dyn]

[12] R.E.A. van Emmerik, S.W. Ducharme, A.C. Amado, J. Hamill (2016) Comparing dynamical systems concepts and techniques for biomechanical analysis
J Sport Health Sci, 5 (2016), pp. 3-13

[13] Mudelsee M (2003) Estimating Pearsons Correlation Coefficient With Bootstrap Confidence Interval From Serially Dependent Time Series
Mathematical Geology, Vol. 35, No. 6

[14] Angela C. Estampador *et al.* (2014), Infant Body Composition and Adipokine Concentrations in Relation to Maternal Gestational Weight Gain, *Diabetes Care, Volume 37*

[15] Angela C Estampador, Paul W Franks (2014), Genetic and epigenetic catalysts in early-life programming of adult cardiometabolic disorders, Dovepress:
http://dx.doi.org/10.2147/DMSO.S51433

[16] Jeremy Pomeroy, Frida Renstrom, Paul W Franks *et al.*, (2013) Maternal Physical Activity and Insulin Action in Pregnancy and Their Relationships With Infant Body Composition, Diabetes Care 36:267-269, DOI: 10.2337/dc12-0885

Supplements

Example of a diary kept by the infants mother.

Startdatum: 11/3 Kl. 10⁰⁰
Stopdatum: 13/3 Kl. 10⁰⁰

Monitor Dagbok

84P077B

Anmärkningen gäller:			Togs av:			Togs på igen:	
Actiheart	Acti-Mini	GENEA	Datum	Kl.	Anmärkning	Datum	Kl.
			12/3	8⁰⁰	Trosan var blöt, pga läkande blöja...	12/3	15³⁰
			12/3	12⁴⁵	Tog bort båda monitorerna		

Startdatum: 11/3 Kl. 10^{00}

Stopdatum: 21/3 Kl. 10^{00}

Monitor Dagbok

84P077

Anmärkningen gäller:			Togs av:			Togs på igen:	
Actiheart	~~[illegible]~~ P077	GENEA	Datum	Kl.	Anmärkning	Datum	Kl.
	X		13/3	03.30	Sov utan	13/3	09.00
	X		14/3	00.10	— " —	14/3	09.25
	X		15/3	00.25	— " —	15/3	09.50
	X		15/3	23.45	— " —	16/3	09.40
	X		16/3	23.40	— " —	17/3	06.45
		X	16/3	23.40	— " —	17/3	10.45
	X		17/3	22.35	— " —	18/3	08.50
	X		18/3	22.40	— " — + glömde	19/3	12.15
	X		19/3	22.25	— " —	20/3	10.15
	X		20/3	23...	— " —	21/3	8...
	X	X	21/3	10^{00}	SLUT :)		

Sovschema

Studiekod: 84P077B

Instruktioner:

Markera med ett streck vid vilka klockslag och under hur lång tid ditt barn sover (enligt exemplet nedan) under de 5 efterföljande dagarna till erat besök.

		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Mån																									

Datum: 090312 OD

		00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Mån	5																								
Tis																									
Ons																									
Tor	1																								
Fre	2																								
Lör	3																								
Sön	4																								

Anmärkningar/förtydliganden:

Matdagbok

Studiekod: 84P077B

Dygn (1-5): 1 12/3 00^{00}

Klockslag	Längd	Amning/Tillägg	Ev. mängd	Måltid	Mys	Kräks
03^{40}	10min	Nutramigen	120ml	X		
08^{10}	15min	– " –	150ml	X		
11^{10}	10min	– " –	80ml	X		
13^{30}	15min	– " –	180ml	X		
16^{20}	30min	– " –	170ml	X		
21^{30}	25min	– " –	210ml	X		

Matdagbok

Studiekod:______________

Dygn (1-5): 2

Klockslag	Längd	Amning/Tillägg	Ev. mängd	Måltid	Mys	Kräks
4.00	20min	Nutramigen	190ml	X		
9.00	15min	— 11 —	180ml	X		
12.10	15min	— 11 —	160ml	X		
14.45	10min	— 11 —	110ml	X		
1645	15min	— 11 —	150ml	X		
18.30	10min	— 11 —	120ml	X		
23.30	15min	— 11 —	200ml	X		

Matdagbok

Studiekod:_______________

Dygn (1-5): 3

Klockslag	Längd	Amning/Tillägg	Ev. mängd	Måltid	Mys	Kräks
05.40	10min	Nutramigen	140ml	X		
09.30	10min	—‖—	130ml	x		
12.10	15min	—‖—	80ml	x		
14.30	15min	—‖—	120ml	X		
17.00	10min	—‖—	80ml	X		
19.00		—‖—	80ml	X		
23.50	10min	—‖—	140ml	x		

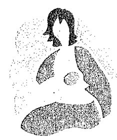
Matdagbok

Studiekod:_______________

Dygn (1-5): 4

Klockslag	Längd	Amning/Tillägg	Ev. mängd	Måltid	Mys	Kräks
06.05	15min	Nutramigen	200 ml	X		
10.00	5min	—"—	50ml	X		
11.45	15min	—"—	180ml	X		
15.00	10min	—"—	120ml	X		
17.30	10min	—"—	120ml	X		
19.20	15min	—"—	200ml	X		

Matdagbok



Studiekod: ______________

Dygn (1-5): 5

Klockslag	Längd	Amning/Tillägg	Ev. mängd	Måltid	Mys	Kräks
04.45	15min	Nutramigen	X 160ml	X		
08.30	10min	— " —	X 140ml	X		
11	10min	— " —	80ml	X		
14.45	15min	— " —	190ml	X		
17.00	10min	— " —	80ml	X		
19.20		— " —	50ml	X		

Kompletterande uppgifter

Efter femdagarsperioden vill vi att Du antecknar två saker:

1) Om detta varit fem vanliga dagar eller om det hänt något speciellt (sjukdom, resa etc)

Har ungefär varit som fem vanliga dagar. Dag 4 verkade inte helt OK ~~men~~ och åt lite mindre.

2) Om Du undvikit något livsmedel till barnet pga misstanke om allergi/överkänslighet.