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Dual Air – Results and observations

Distriktsforsk project on the feasibility of automatic detection of right and wrong use of the Dual Air hairdryer

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Proof of concept automatic detection
This report summarizes a proof-of-concept study of the feasibility of developing a smart Dual Air blow-dryer that automatically provides feedback on its use. We successfully demonstrated feasibility by automatically identifying the right and wrong use of Dual Air by using machine learning on data from IMU sensors mounted on the blow-dryer. Video pose estimation from the study also documented that the Dual Air hairdryer allows hairdressers to perform similar blow-drying operations with a significantly lower arm elevation angle than with conventional hair dryers. A data collection protocol with hairdressers, a comprehensive dataset, and a framework for analysis and further testing and model development was built to serve as a starting point for a more robust product-ready usage-prediction tool.

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Klikk eller trykk her for å skrive inn tekst.

Summary

This report summarizes a pre-project funded by Distriktforsk. The purpose of the project was to explore opportunities for developing a smart Dual Air blow-dryer that provides real-time automated feedback to hairdressers using sensors.

In July and August 2021, Dual Air and SINTEF conducted a study on hairdressers in Trondheim, Bergen, Oslo, and Sandnes using the Dual Air blow-dryer. Sensor and video data were collected from 20 hairdressers at their workplaces, together with a written description of hairdressing techniques and the use of the Dual Air. Sensors used for data collection were seven wireless tri-axial accelerometers on the bodies of the hairdressers and two Inertial Measurement Units (IMUs, including a tri-axial accelerometer and a tri-axial gyroscope) on the hairdryer. We also captured video of the blow-drying operations.

Results from this study show that it is feasible to automatically identify the right and wrong use of Dual Air by using IMU sensors and a trained machine learning model (Long-short term memory neural network - LSTM). However, a larger dataset including a variety of techniques and instances of improper use will help to improve the performance of the chosen LSTM model.

We used video for a movement and posture analysis, comparing blow-drying operations using Dual Air and a conventional blow-dryer. Our results show that the Dual Air hairdryer allows hairdressers to perform similar blow-drying operations with a lower shoulder abduction angle and arm position than conventional hair dryers. A larger study is required to estimate the exact difference.

Finally, we demonstrated the feasibility of a data collection protocol with hairdressers and have built a comprehensive dataset and analysis framework for further testing and model development as a starting point for a more robust product-ready usage-prediction tool.

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1 Introduction

The project report is written in the scope of the Distriktforsk project (Tilsagnsnr: DFFOR 21.03): *Dual-Air*. The project was carried out from June to October 2021. The main goal was to: Explore opportunities to provide real time automated feedback on the use of Dual Air using sensors.

Background on the Dual Air hairdryer and the reason for this project

Dual Air is developed and produced in Norway. It is a blow-dryer that represents something fundamentally new for hairdressers. Traditional hair dryers have "gun grips" and are designed for consumers. Dual Air is designed to solve one of the biggest sustainability problems in the hairdressing industry - strain injuries because of blow-drying hair. The Dual Air is a professional hairdryer that aims at solving both physical strain and, in addition, is a more precise work tool with increased efficiency.

Almost twenty years ago it was pointed out that as many as 50 % of hairdressers struggle with health problems, of which 75 % have neck and shoulder problems[1]. Little improvement has happened since then, a recent scoping review shows that hairdressers have a high prevalence of work-related musculoskeletal disorders, especially in the back, neck and shoulder region[2]. Compared to other occupations, hairdressers have a higher risk of leaving their profession early for health reasons. The idea behind the Dual Air hairdryer is that it provides an ergonomic working position where the arm, elbow and shoulders can be lowered. Hairdressers who use Dual Air say that its ergonomic advantages have given them several new decades in the profession (in feedback to Dual Air). Hairdressing schools in Norway have embraced the hairdryer, and reportedly 60 % of hairdressing schools currently use Dual Air. They report that their students show great enthusiasm for the dryer, and in comparison to their older peers, they report no challenges in teaching students to use it. The Dual Air hairdryer is also used in many hair salons, with a reported market share of around 10 %. For Dual Air to succeed with the hairdryer, the hairdresser must learn to use the hairdryer correctly. In principle, this should be easy and quick to learn, but hairdressers who work with traditional hair dryers must un-learn old techniques to succeed. Before the pandemic, Dual Air conducted physical salon visits to provide training. However, physical training is expensive and very labour-intensive for Dual Air as a supplier.

Covid-19 has shown that it is not only necessary, but also feasible, to look at alternative ways of delivering this training. The question arose: Can the hairdryer itself provide the hairdresser with the necessary training? If yes, this would significantly increase the scalability of Dual Air and ease a potential international rollout.

Goals for the project:

From the proposal, the main goal:

Explore opportunities to provide feedback on the use of Dual Air using sensors.

Sub-goals:

- Testing and collection of test data with simple sensor platforms to identify and specify technical requirements for sensors and location (reasonability assessment).

[1] Folkenborg, K., Jordfald, B., & FAFO. (2003). Frisørundersøkelsen 2003. In FAFO (Vol. 421): FAFO.

[2] Kozak, A., Wirth, T., Verhamme, M., & Nienhaus, A. 2019. Musculoskeletal health, work-related risk factors and preventive measures in hairdressing: a scoping review. ***Journal of Occupational Medicine and Toxicology***, 14(1): 24.

- Exploratory data analysis to assess the sensor platforms' ability to describe usage patterns and working postures, including developing simple *pattern recognition algorithms* (feasibility study).

Dual Air is already a high-tech hairdryer. Unlike most hairdryers, it is equipped with a microcontroller. This reduces the cost and complexity of equipping the hairdryer with sensors. The question was whether we would be able to use sensor data to automatically understand and detect how the dryer is held and used, which in turn could be used to provide direct feedback to the user in both correct and incorrect use (haptic or audio / visual feedback).

The pre-project summarized in this report is a proof of concept on whether sensors can recognize human activity so that it is probable that a sensorised hairdryer can provide the hairdresser with feedback on use.

2 Data collection

The data collection protocol consisted of the setup and placement of seven Axivity AX3[3] sensors on the right and left upper arms, wrists, and hips, as well as on the back of volunteer hairdressers (Fig 1.). Axivity sensors collected acceleration data at a sampling rate of 100Hz.

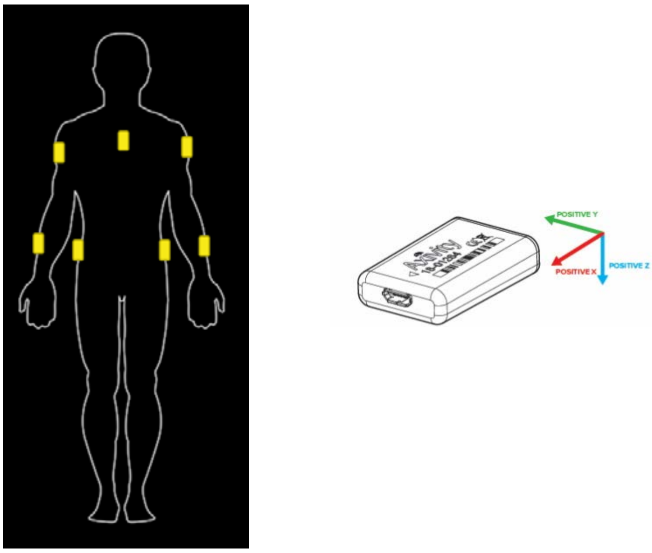


Figure 1 Right: Axivity sensor diagram with axes configuration. Left: Axivity sensor placement

Sensors placed on Dual Air blow-dryers

Two GaitUp Physilog[4] IMUs were set up and placed on the body of the hairdryer, collecting acceleration and angular velocity in three directions at 128Hz

[3] https://axivity.com/product/ax3
[4] https://research.gaitup.com/physilog/

Figure 2 Right: Hair dryer with sensors. Left: Using the dryer with sensors.

Video of blow-drying operations

A GoPro camera mounted on a tripod was used to record all blow-drying operations. The purpose was threefold

1) To create a reference for sensor synchronization
2) To make possible detailed and time-stamped annotation of arm- and blow-dryer position for use in training and validating a machine learning algorithm
3) To extract additional movement and posture data using pose estimation analysis methods

A written record of the participants' use of the Dual Air, with instances of wrong use, hairdressing technique, and time was compiled for all participants (see example in Figure 3) based on the video recordings.

Filnavn:	Dato forsøk	Start tidspunkt
GH011368 og GH021368	20210713	10:24

Minut og sekund i video:		Feil eller Riktig bruk	Teknikk	Kommentar
Fra	Til	F / R / N		
02:07	02:15	R	Synkronisering	
02:18	03:58	F	Tørker vann ut av håret, rist	feil grep, viften på føneren vender ut fra kroppen hennes i stedet for inn mot overarmen
04:01	04:30	R	Deler opp håret	Føner legges ned
04:30	05:30	F	Føner nakke	Feil grep fortsatt og rister litt
05:30	05:52	R	Deler opp håret	Setter føner fra seg i hoder
05:52	07:11	F	Føner bakhodet	Feil grep fortsatt
07:11	09:31	N	Instruksjon	
09:31	10:40	R	Føn bakode	
10:41	11:09	R	Inndeling	Setter føner fra seg
11:10	11:19	F	Tar opp føneren i feil grep	
11:19	13:13	R	Følning kun ovenfra	
13:13	13:16	N	Instruksjon snu luft	
13:16	14:09	R	Føning ovenfra	
14:09	15:37	N	Inndeling og instruksjon	Setter føner fra seg, jeg instruerer med føner i hånden
15:38	17:23	R	Føner fra oversiden sidepartier	
17:23		R	Kroneparti under og over	
GH021368				
00:10	02:01	R	Føning under og over	
02:03	02:38	N	Inndeling	Setter føner fra seg
02:38	04:27	R (med føner)	Føning sider under og over	Løfter overamen børstearm
04:27			Flytter kamere	
04:28	07:17	R	Føning overhår under og over	
07:17	07:23	N	Bikker føner unna for å lytte til meg	
07:23	08:46	R	Føner lengder overhår	
08:46	09:07	R	Kroneparti under og over	
09:07	09:43	N	Instruksjon Børste	
09:43	11:23	R	Føning ounder og over	
11:23	16:22	R	Føning overhår under og over	
16:28	17:22		Instruksjon	

Figure 3 Written register of participants' use of Dual Air

All data recording sessions started with a calibration procedure to facilitate the synchronization of data. Participants were asked to place the Dual Air on a table, stand still for 10 seconds, grab the Dual Air, perform a jump, leave the Dual Air back on the table, and stand still for another 10 seconds before starting with their normal hairdressing routine.

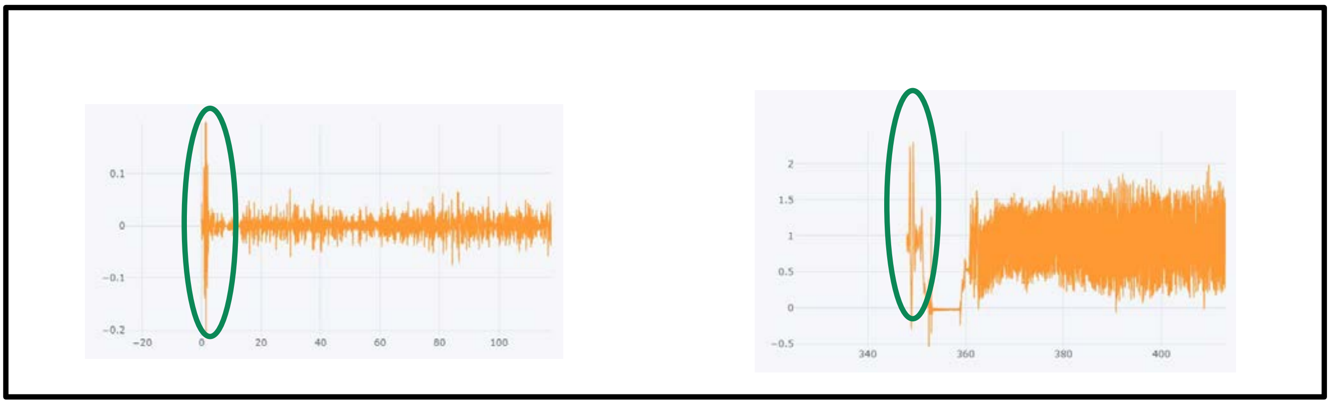


Figure 4 Left: Vertical acceleration data from the Axivity sensor on participant back. Right: Vertical acceleration data from the GaitUp sensor on the Dual Air. Jump is clearly identifiable in both time series and was used to synchronize data from all sensors

3 Methods

All collected data was uploaded to a server for subsequent analysis. Both Axivity and GaitUp data were read and processed using custom-made Python scripts. The pre-processing consisted of data synchronization and segmentation using the synchronization jump, as well as video and written records as references.

Accelerometer data were low-pass filtered using a sixth-order Butterworth filter with a cut-off frequency of 2 Hz. The upper and lower arm angle (°) in relation to the line of gravity was then calculated as $\arccos(A\text{x}/(A^2\text{x} + A^2\text{y} + A^2\text{z})^{1/2})$, where Ax, Ay, and Az were the filtered signals for the three axes of the corresponding accelerometer and *X-axis* was the vertical direction. Sensor data were then resampled to 100Hz to match the temporal resolution among all datasets.

Annotations on instances of right and wrong use of the Dual Air were coded based on manual analysis of video recordings and synched with sensor data.

All pre-processed synchronized data was then arranged in a n x m matrix for each participant.
Data from Axivity sensors, arm angle, technique annotations, GaitUp sensors are shown in Figure 5.

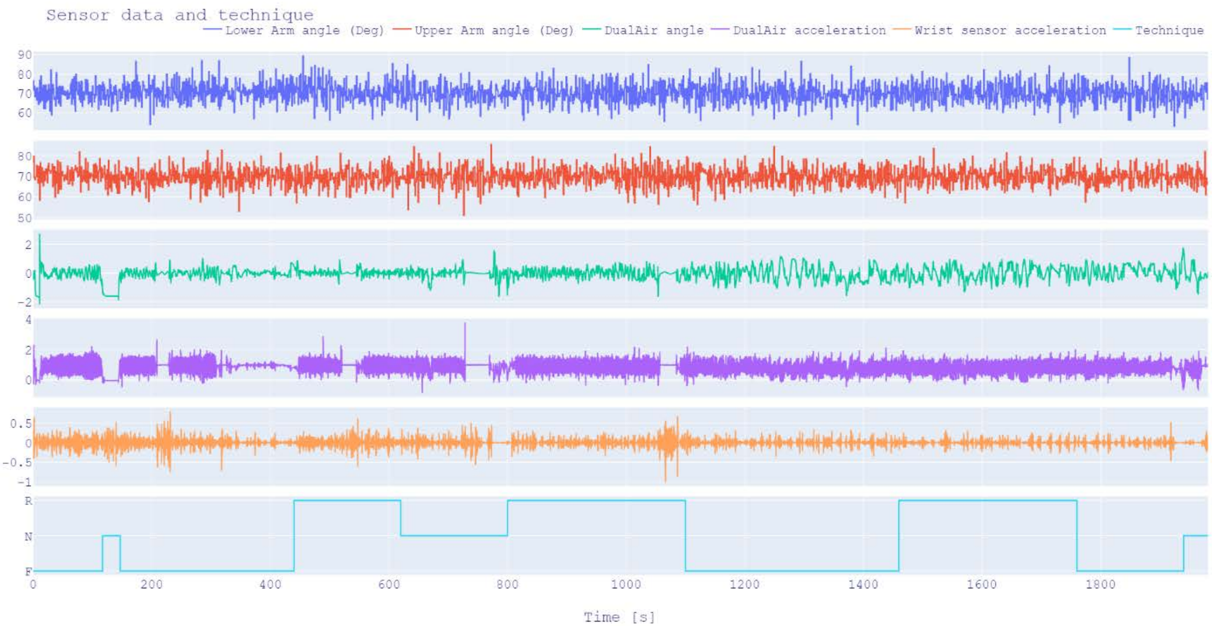


Figure 5 Visualization of technique (right or wrong) and sensor synchronized data from one participant

In order to test for automatic classification of right or wrong use of Dual Air, the data was fit into a Long Short-Term Memory (LSTM) deep neural network algorithm. LSTM models are particularly suited for sequential data, and previous applications include the automatic classification of arm movements during interactions with objects[5] [6].

[5] Tabrizi, S. S., Pashazadeh, S., & Javani, V. (2021). A Deep Learning Approach for Table Tennis Forehand Stroke Evaluation System Using an IMU Sensor. *Computational intelligence and neuroscience*, *2021*.
[6] Luo, C., Feng, X., Chen, J., Li, J., Xu, W., Li, W., ... & Zomaya, A. Y. (2019, April). Brush like a dentist: Accurate monitoring of toothbrushing via wrist-worn gesture sensing. In *IEEE INFOCOM 2019-IEEE Conference on Computer Communications* (pp. 1234-1242). IEEE.

The LSTM model consisted of three LSTM hidden layers with 512, 256, and 128 units, respectively, followed by a fully connected layer and a final output layer.

The machine-learning algorithm was trained and tested based on manual annotations of arm posture and use of Dual Air, with input data (X) being the series of features obtained from sensor data (upper and lower arm acceleration, upper and lower arm angles, dual air acceleration and angular velocity). Model output (Y) estimates correct or incorrect use of Dual Air Figure 6.

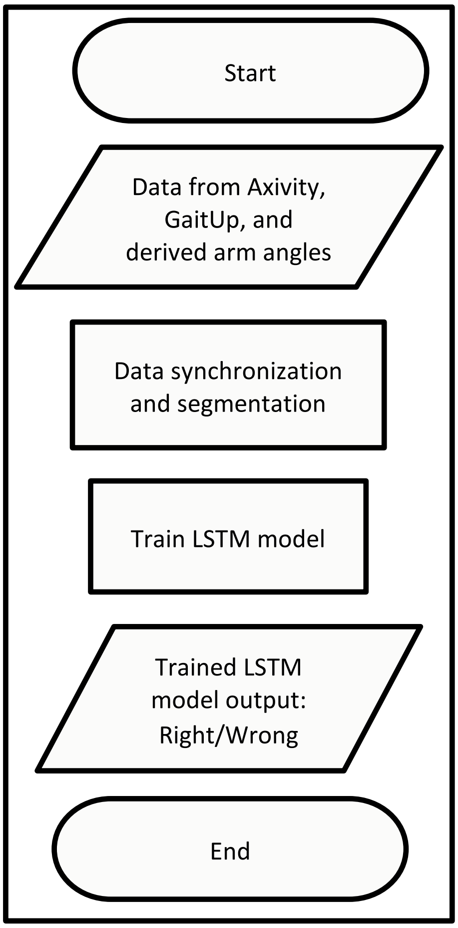


Figure 6 Flowchart of training and testing process of the LSTM model.

4 Observations and Results

4.1 Overview

We collected data from a total of 20 hairdressers during normal blow-drying operations:

- Average number of data samples collected per participant: 138 700 (1387 s)
- Standard deviation of number of samples collected per participant: 68249 (682 s)
- Minimum number of samples collected for one participant: 30 100 (301 s)
- Maximum number of samples collected for one participant: 246 100 (2461 s)
- Number of participants using a traditional hair dryer during part of the data collection: 11
- Number of participants with high (shoulder abduction larger than 50 degrees) arm posture during use of Dual Air: 11 (55 %)
- Number of participants with high arm posture during use of a different dryer: 8 (73 %).

- Percentage of time of use of Dual Air with high arm posture: 9 %
- Percentage of time of use of conventional hairdryers with high arm posture: 34 %

4.2 Sensor Data

Our main purpose was to explore the feasibility of automatically detecting the wrong use of Dual Air blow dryers based on sensor data. If feasible, this could enable real-time feedback for onboarding and technique training. It could make a truly smart blow dryer possible.

We successfully collected sensor data from 20 normal blow-drying operations conducted by trained hairdressers, of which only 5 had previous training in the use of Dual Air. Even so, instances of wrong arm position and/or grip were limited. The distribution of instances of wrong use among participants was also spread out in time and among participants, with reports from some participants indicating no instances of wrong arm position (see Figure 7)

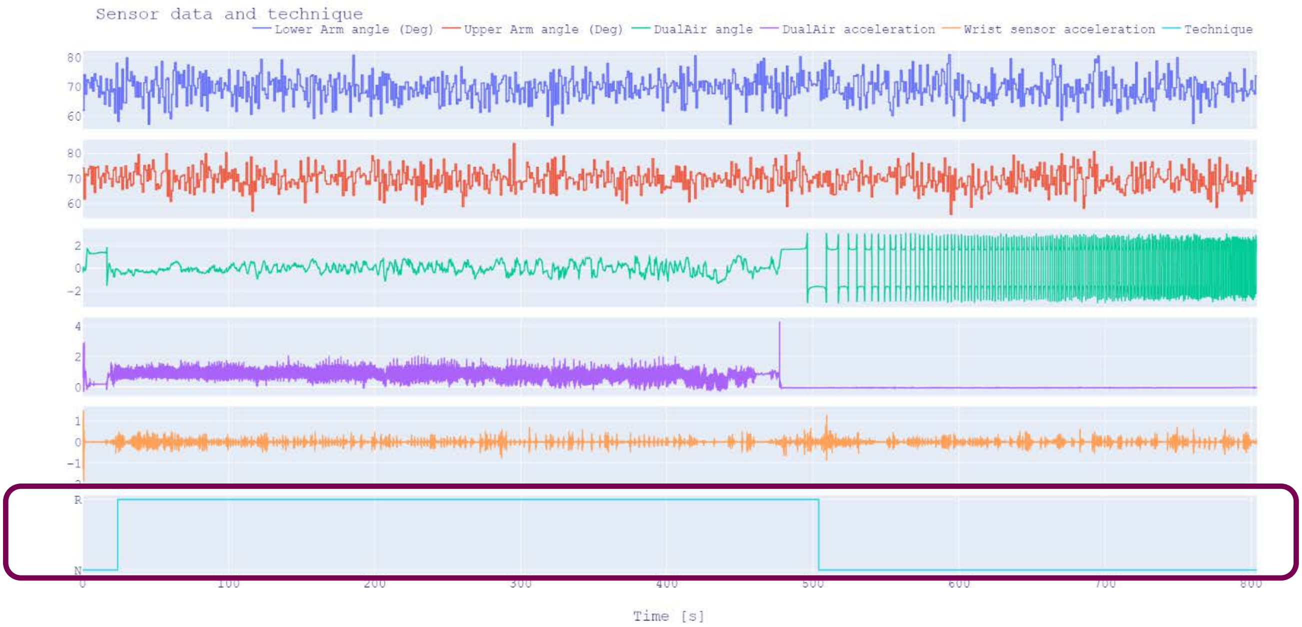


Figure 7 Data from one participant with no annotated instances of wrong use of Dual Air

For 11 of the sessions, the hairdresser used a non-instrumented conventional hairdryer for part of the session, with varying duration. Figure 8 shows the change from Dual Air to non-instrumented conventional blow-dryer in the synchronized time series of sensor data.

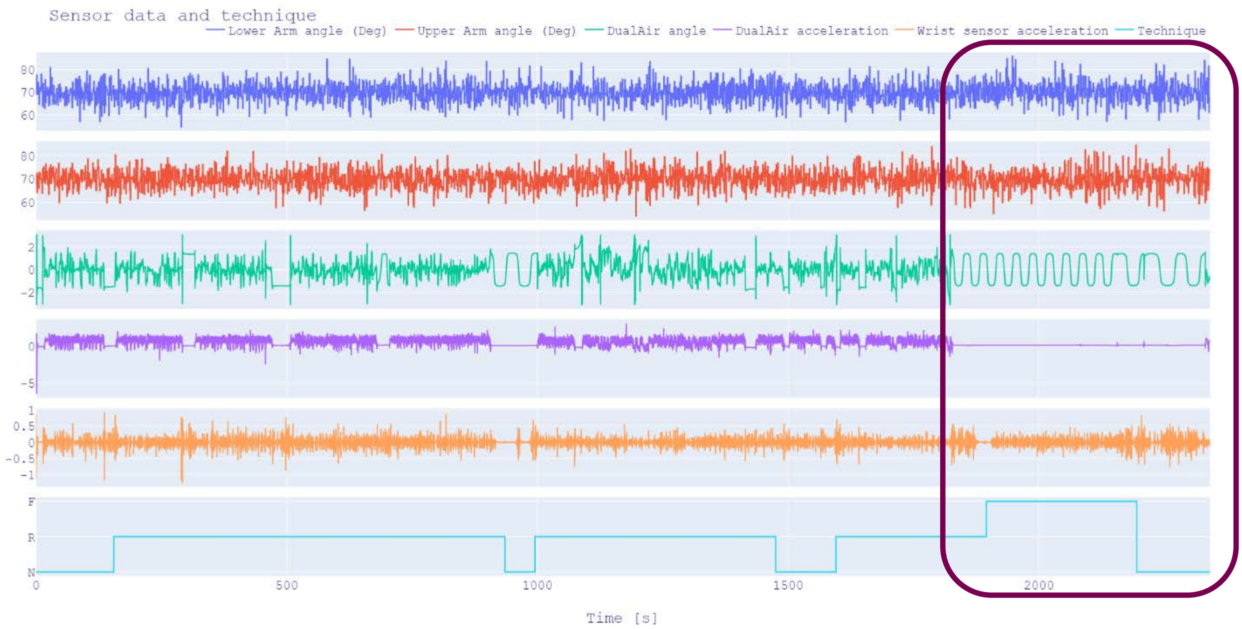


Figure 8 Data from one participant switching from Dual Air to a conventional blow-dryer. Towards the end of the plots, data from sensors mounted on Dual Air is at zero or noise level, while data from the body sensors still show movement.

4.3 Video Pose Estimation

In order to visualize the differences in arm posture between instances of the use of Dual Air and instances of the use of a conventional hairdryer, video pose estimation was applied on 4 randomly selected video recordings. The extracted positions of key points on the shoulder and elbow of the user were used to compute an estimation of shoulder abduction angle (Figure 9, Figure 10, Figure 11)

Figure 9: Automatically generated key points from video recordings. The coordinates of elbow and shoulder were used to estimate and compare shoulder abduction. Left: Conventional hairdryer. Right: Dual Air

Figure 10 Shoulder angles for periods of use of Dual Air and a conventional hairdryer. Higher during use of conventional hairdryer during similar techniques. Data from 4 participants.

Figure 10 Compares shoulder angle for similar technique using Dual Air and a conventional blow-dryer. It clearly illustrates that the design of the Dual Air allows hairdressers to perform similar techniques with lower shoulder abduction.

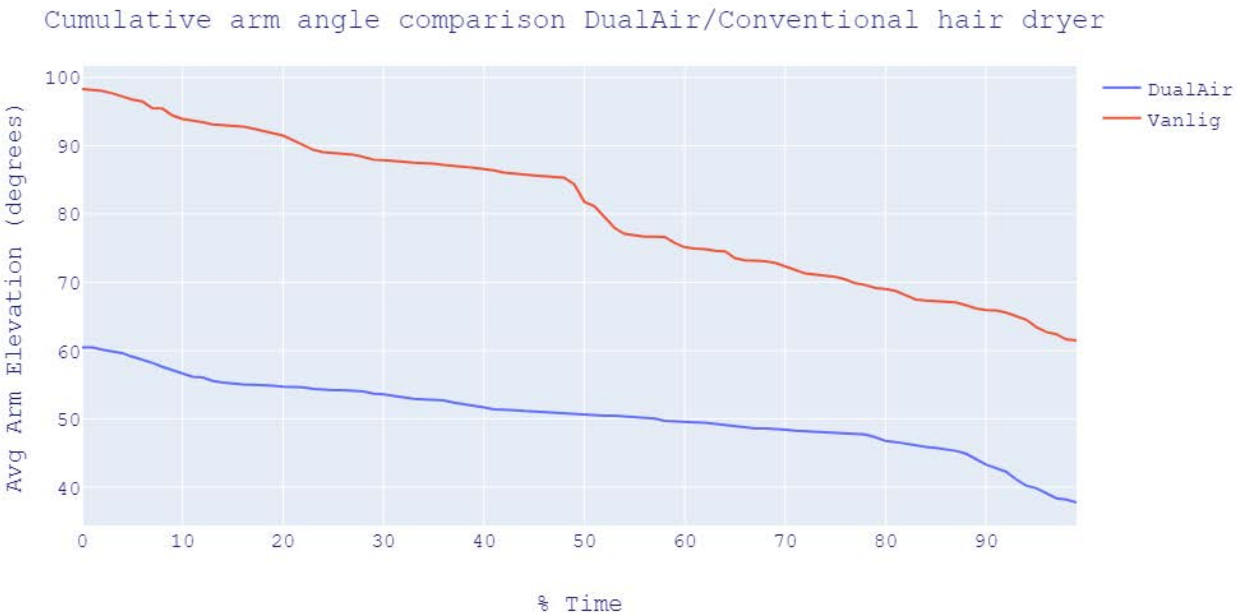


Figure 11 Cumulative shoulder angles for periods of use of Dual Air and a conventional hairdryer. Higher during use of conventional hairdryer during similar techniques. Data from 4 participants.

Wrong arm position observed in 71 % of instances of the use of a conventional hair dryer was generally described as high arm position, indicating high shoulder abduction angle. The design of Dual Air allows hairdressers to perform similar techniques with lower shoulder abduction.

Figure 11 compared the average arm angle for the entire blow-drying operation of 4 participants using a Dual Air and a conventional blow-dryer. The graph shows a clear reduction in arm angle when using a Dual Air, compared with using a conventional blow-dryer. While participants spent less than 5 % of the Dual Air operation with their arm over 60 degrees, more than 20 % of the conventional operation was spent with an arm angle over 90 degrees.

Although video pose estimation provides an alternative for sensor-less assessment of movement patterns, it demands long computing times and requires the development of robust, specific models for reliable use in larger datasets.

4.4 Deep Learning – Classification of right and wrong use

We successfully used an LSTM model to automatically detect instances of wrong use of Dual Air blow-dryers based on data from sensors mounted on the Dual Air.

Performance of the LSTM model was assessed by root mean square error (RMSE) and compared between models with different parameters (epochs number, batch size, number of layers) to find the best network performance. Parameters were tuned following a trial-and-error method, as there is no universally accepted method for optical selection of network configuration.

Overall, results show an improving wrong/right prediction performance with an increased number of epochs and reduction of batch size, with the model accurately predicting starting point of correct use but failing to predict continuous right use Figure 12

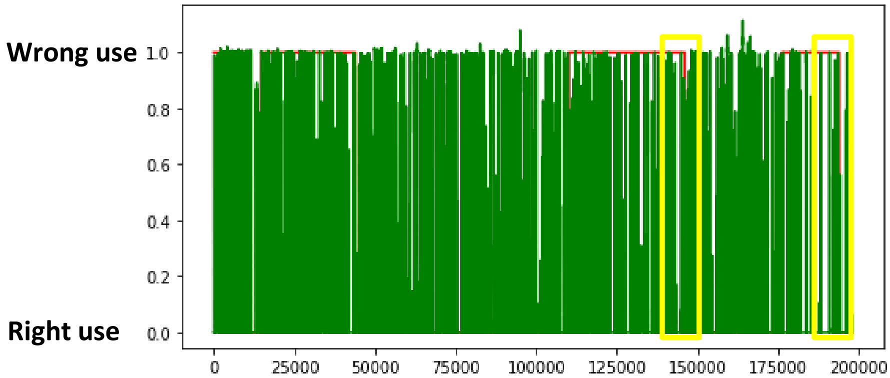


Figure 12 Prediction output for one participant (in green) and annotated use (in red, wrong=1 and right=0). Note how the prediction accurately goes to 0 when correct use starts but fails to correctly predict continuously

LSTM models can be significantly improved by further tuning of parameters, with optimal models requiring long training time and high computing performance. On the other hand, prediction performance can be severely affected by the amount of data, including annotations.

While we have successfully demonstrated the feasibility of automatic detection of wrong use of Dual Air based on real-time data from sensors placed on the blow-dryer, much more data is required in order to improve the model to a product-ready level. A larger research project with a much higher number of participants would be ideal. Such a project should also explore how the Dual Air blow-dryer could provide real-time feedback to hairdressers to ensure that they learn proper Dual Air techniques. A larger sample with more right and wrong instances would probably also lead to better performance models.

5 Summary and Conclusion

The purpose of this project was to explore opportunities to provide real time automated feedback on the use of Dual Air using data from sensors placed on the blow-dryer. We successfully demonstrated the feasibility of automatically detecting instances of wrong use – the necessary basis for automatic feedback. Moreover, we were able to measure shoulder angles and corresponding arm position during hairdressers' blow-drying operations on regular customers, using video pose estimation. Our results show that blow-drying regular customers with Dual Air are done with a significantly lower arm position than when using conventional blow-dryers. While there is a clear difference, accurate estimation of the difference requires a larger follow-up study with more participants.

The results were presented during a Teams video meeting with stakeholder from the hairdressing industry and researchers. A number of comments were made, also with regards to the focus of a possible future research project.

> *"It is important to start with the newly trained, or those that are still learning. Learning is essential to using the Dual Air hairdryer correctly. If that can be helped with sensors, it would be a smart way to solve it. Important to also check onboarding for those that have been working in the industry for quite some time."*
>
> *"If new versions and new tools come to the market, the easiest is to test and verify with newly the trained. Also getting it accepted and to market, can happen through the hairdresser schools."*
>
> *"If the ergonomics is so profoundly better as shown, we hope that the hair salons at least ensure that new hairdressers can continue use from the hairdresser schools when they start working, giving them an ergonomically better posture"*
>
> *Ergonomics researcher: "The amount of time the arm position is away from the side of the body (shoulder abduction), is what causes physical strain. Standing with high shoulder abduction over time, even with a light object, can cause physical strain. When shoulder abduction is very low, weight is of much less influence. So, standing with low shoulder abduction with a heavy object can have a lower impact physically than standing with a light item with high shoulder abduction."*

The meeting participants supported the idea of developing a smart Dual Air, capable of supporting learning and un-learning, as a promising approach to scaling Dual Air.

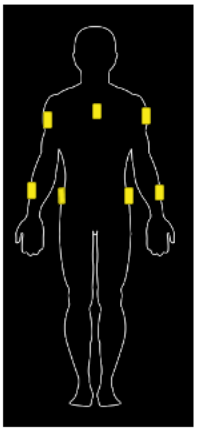
Results from this study show that it is feasible to automatically identify right and wrong use of Dual Air by using IMU sensors. A larger dataset including a variety of techniques and instances of wrong use will help to improve the performance of the chosen LSTM model. This is necessary if the model is to be successfully applied to support automated learning of correct use. We demonstrated the feasibility of a data collection protocol with hairdressers and have built a comprehensive dataset and analysis framework for further testing and model development as a starting point for a more robust product-ready usage-prediction tool.

Our movement and posture analysis suggest that the Dual Air hairdryer allows hairdressers to perform similar blow-drying operations with a significantly lower shoulder abduction angle and arm position than with conventional hair dryers. A larger study is required to estimate the exact difference.

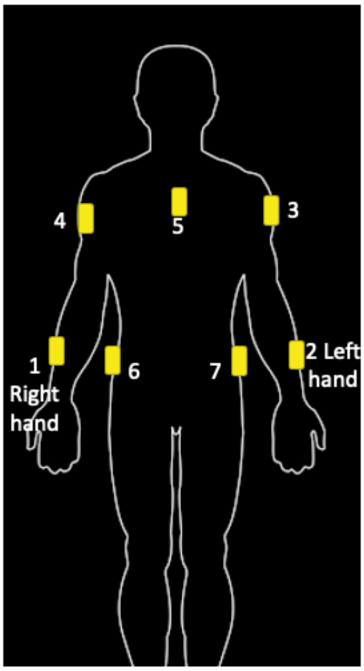
The data collection protocol and data analysis pipeline developed in this project will positively impact future projects, significantly reducing the time required to plan and conduct data collection and providing a framework for analysis and automatic identification of wrong use of Dual Air.

A Sensor placement and setup procedure before experiment

AX3 Axivity Sensor placement



Sensor must be oriented as follows:
- X-axis pointing downwards,
- Y-axis pointing sideways
- Z-axis pointing outwards from the body surface (the serial number side of the accelerometer should be in-wards)



2

Manual on how to prepare the sensors: (1/2)

- Charge the Axivity sensors
- Charge the **Physilog** sensors (on the **DualAir**)

- For **Physilog**, they will flash red and green while charging, fully charged/ready: **stable green light**.
- For **Axivity** it will slowly fade and come back in different colors
- (0-50% red and fading)
- (50-95% red and green and fading)
- (95-100% blue, red and green and fading) → ok to disconnect when all three fade and come back.
- 95% charge is enough for 2 weeks of measurements.

Axivity sensor

3

Charge indication sensors charging/vs ready

Axivity sensors:

Axivity sensor = charging

Axivity sensor = ready

Physilog:

Physilog sensor = charging

Physilog sensor = ready

Gopro:

GoPro = charging

GoPro = ready

4

Manual on how to prepare the sensors: (2/2)

- Charge the GoPro/Axivity/Physilog

At the hairdesser:

- Switch on the **GoPro** press the red button on the top, and it start and after 5-10 seconds it starts recording.
  - Position the GoPro so you can see the hairdresser best.

- Switch on the **Physilog** sensors (on the DualAir):
  - hold the on/off button for 5 seconds:
  - It starts flashing very shortly green = recording.

- Axivity = always on.

5

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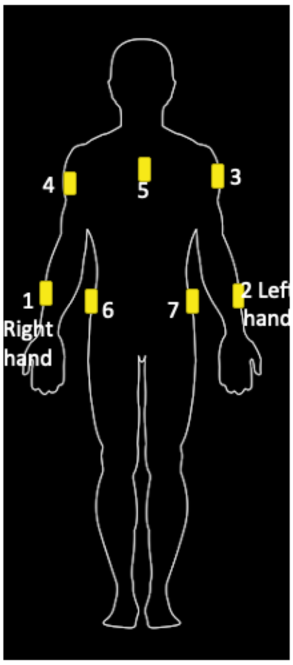
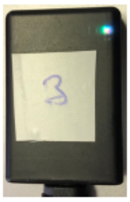
Placing of the sensors on the body:



- Place the sensors as shown. Number 5 is on the back (above bra strap).
- Use double sided tape over the Axivity letters (that side will be towards the body.
- While standing still and holding arms along side body the numbers (1-7) should be readible
  (so NOT upside down)
- Extra check: charge port = downwards
- Sensors on skin, not on cloth



6

Hop procedure – before experiments

- The GaitUp sensors are sensitive, so we made the precedure a little different.
- Place the DualAir (with sensors) down for 10 seconds.
- Pickup the DualAir with both hands and make a good hop.
- Put down the DualAir and stand still for 10 seconds
- Go ahead with your work/the experiment.

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Last checks:

- Physilog sensor on?
- GoPro taking video? (red flashing light, (screen can be black, you can tap on it once, so it turns on again, on the top it shows a red dot while recording).
- Axivity sensors are placed correctly?
- Go to test logbook (next step)
- ***LET THE SUBJECT PERFORM A HOP TO SYNC SENSORS! (but note the time first, see next slide)***

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Test logbook:

Test number/location	Date	Start-Time	Stop time	Technique or right/wrong use	Comments