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Relevance of anthropometric measurements as predictors of prevalent diabetes type 2: a cross-sectional study on a Norwegian population

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ABSTRACT

Objectives The objective was to determine the predictive potential of anthropometric indices to screen prevalent diabetes mellitus type 2 in a Norwegian population.

Design This is a cross-sectional design to determine the potential association of waist-to-height ratio (WHtR), waist-to-hip ratio (WHR), waist circumference (WC) and body mass index (BMI) with prevalent diabetes mellitus type 2 through logistic regression analysis. Receiver operating characteristic (ROC) curves were used to determine the predictive potential of the anthropometric indices. Youden's index was applied to determine the optimal cut-off points for each anthropometric index.

Setting This study used cross-sectional data from the populations-based Health Study in Nord-Trøndelag which invited all citizens in the county above 20 years of age.

Participants This study included all those who were non-pregnant and had complete data (N=50 042), 98.5% of the participants. The sample is to be considered representative for the population of Norway.

Primary and secondary outcome measures OR and ROC of the potential association between diabetes mellitus type 2 and anthropometric indices were the main planned and performed outcome measures.

Results The results suggest that the anthropometric indices performed differently within the Norwegian population with WHR and WHtR being the stronger predictor with (ROC) of 0.746 (0.735 to 0.757) and 0.741 (0.730 to 0.752). The predictive potential for the investigated anthropometric indices was generally stronger for women than men.

Conclusion Anthropometric indices of size BMI and the highly correlated WC are less associated with prevalent diabetes mellitus type 2 than WHR (WC adjusted for hip circumference) or WHtR (WC adjusted for height) in a Norwegian population.

Strengths and limitations of this study

- ► Sample of 50 042 participants.
- ► The optimal cut-off values were calculated using Youden's index.
- ► Potential confounders as physical activity and diet were not calculated for in the regression model.
- ► We address only the population prevalence of diabetes mellitus type 2, but not the severity or complications.

BACKGROUND

It is estimated that 415 million people in the world suffer from some form of diabetes. Of those, 46.5% are undiagnosed. By 2040, the International Diabetes Federation (IDF) predicts that 642 million people will have diabetes mellitus type 2 (DMT2).[1] It is also estimated that 318 million adults have impaired glucose tolerance, which is a form of pre-diabetes. Estimates from the WHO tell us that high blood glucose counts as the third highest risk factor for premature mortality.[2] Over 2.2 million deaths were caused by complications of high blood sugar in 2012 and 1.5 million deaths were attributable to diabetes.[3] DMT2 counts for 90%–95% of all diabetes cases worldwide.[4]

According to the Diabetes Atlas ninth edition, 3.6% of the population between 20 and 79 years of age in Norway had diabetes in 2010 and 5.3% in 2019. About 90% of all diabetes cases were DMT2. The projection for the year 2045 is 6.7%.[1]

Anthropometric measures such as body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHtR) and waist-to-hip ratio (WHR) are associated with prevalence of diabetes DMT2.[5–7] Even those who are not classified as obese or overweight by BMI may still have a higher ratio of central body fat and this may increase the risk of DMT2.[8] However, the association appears to vary by gender and between ethnicities.[6–8] Indicators of overweight and central obesity are therefore important factors to be able to early identify those individuals with prevalent DMT2. Such indicators are also often incorporated in general guidelines for early detection of diabetes.[9]

Several studies have indicated that both WC and WHtR seem to perform better as a

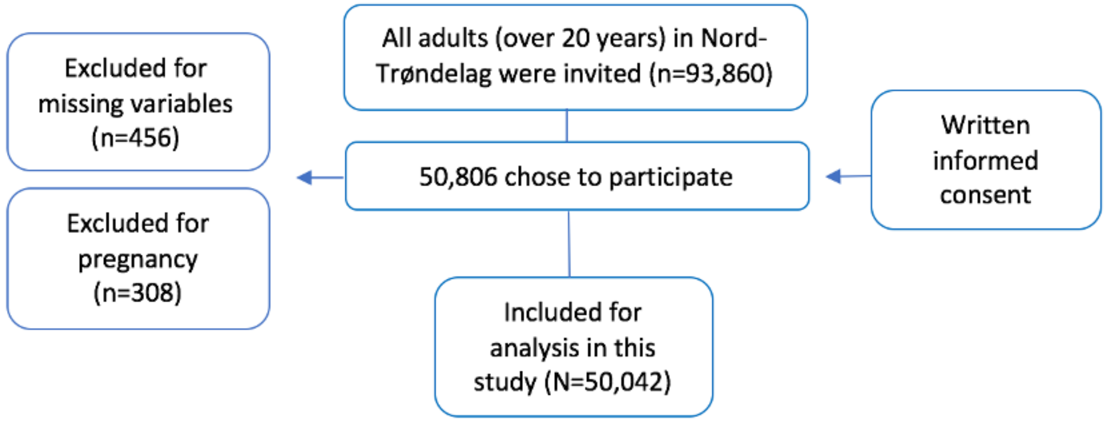

Figure 1 Data collection flow chart.

predictor of DMT2 compared with BMI, with receiver operating characteristic (ROC) values.[10]

A study from 2010 suggested that there is no anthropometric measure that could perform across ethnicities; the authors found a large variation on the predictive potential of anthropometric measures with DMT2, based on ethnicity and sex.[11]

To our knowledge, there have been no studies that investigate the association between DMT2 and different anthropometric indices in Norway using a larger, population-based data sample. This study investigated the prevalence of DMT2 in a Norwegian population with the objective to determine the predictive potential of four anthropometric indices to screen prevalent DMT2 in this population: first, we determined the *association* of WHtR, WHR, WC and BMI with prevalent DMT2; second, we estimated the optimal cut-off points for the same factors to *predict* prevalent DMT2. This may be of clinical and public health value by contributing to the understanding of which anthropometric measurement performs best in terms of predicting prevalent DMT2 in a Norwegian population.

METHOD

Data collection

Data from 50 042 individuals (out of 93 860 invited, see figure 1) who participated in the third wave of the Norwegian population-based cohort study: the Nord-Trøndelag health study (HUNT) were analysed. There have been three waves of data collection so far: HUNT1 (1984–1986), HUNT2 (1995–1997) and HUNT3 (2006–2008), with a fourth currently ongoing (2018). This study used the cross-sectional data from the third wave of data collection, HUNT3. The population in the county of Nord-Trøndelag is relatively ethnically homogeneous, with only 3% non-Caucasians. It is also considered to be fairly representative for the whole population of Norway in terms of geographical, demographic and employment structures.[12] An invitation with the health questionnaire was sent by mail to all citizens in the county of Nord-Trøndelag who were above 20 years of age. Details concerning the questionnaires and examinations have been described elsewhere.[12]

The individuals who chose to participate completed an extensive questionnaire (including information on previously known diabetes), clinical examination and blood sampling.[12] Weight and height were measured with the participants wearing light clothes and without shoes. WC was measured horizontally at the level of the umbilicus with a non-elastic tape measure when the participants were standing with the arms relaxed. Hip circumference (HC) was measured around the buttocks, below the iliac crest where the circumference appeared to be largest.[12]

Patient and public involvement

Neither patients nor the public were involved in the design phase of this study.

Sample

All data used in this study were de-identified and the authors had no access to any identifier key. This study included all those who were non-pregnant and had complete data (N=50 042, 98.5% of the participants, figure 1) on the variables listed in table 1.

A previous study has validated the self-reported diabetes question in HUNT by comparison with medical records. The result showed that the answers were verified in 96% of the cases.[13] The cut-off levels to define DMT2 used are those recommended by the WHO and the IDF.[14]

Statistical analysis

Normal distribution was assessed and verified using histograms and Q–Q plots. Descriptive statistics of all variables are presented as numerical data. Two-sample t-test was used to show any potential group differences in the data between men and women and between participants with diabetes and without diabetes. For the categorical variables, a $\chi 2$ test was used to compare any potential differences between the groups. All categorical data were expressed as percentages. BMI was presented as a mean and categorised by general overweight cut-offs according

Table 1 Variables included in the analysis

Dependent variables	Definition
DMT2	Stated that diagnoses of DMT2 have been made by a medical doctor*
Independent variables	
Age	Age at the time of the data collection
Sex	Male or female
Smoking	Smoking at least one cigarette per day
BMI	Kilograms/height in square meters
WC	WC in centimetres
HC	HC in centimetres
WHR	WC/HC
WHtR	WC/height in centimetres
Weight	Weight in kilograms
Height	Height in centimetres

*Those who stated that they had diabetes type 1, latent autoimmune diabetes of adults, maturity onset diabetes in young or unspecified diabetes were not included as type 2 diabetes.
BMI, body mass index; DMT2, diabetes mellitus type 2; HC, hip circumference; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

to the WHO.[15] To consider confounding factors for OR, two logistic regression models were developed and applied to determine the association between DMT2 and the anthropometric measures. The first model adjusted for sex. The second model adjusted for sex, age and smoking (yes or no). Smoking has shown to have a clear association with DMT2.[16] The categorical anthropometric measures used were BMI, WC, WHR and WHtR included as independent variables in all two models. Before running the logistic regression models, the continuous anthropometric indices BMI, WC, WHR and WHtR were categorised into four levels using the quartiles of P25, P50 and P75 as cut-off values with the lowest quartiles as a reference.

To determine the predictive potential of the anthropometric measures for DMT2, the ROC curves, area under the curve (AUC) and their 95% CI were calculated for BMI, WC, WHR or WHtR. Since ROCs are unadjusted, these are presented according to sex. A p value of <0.05 was considered statistically significant in the analysis.

The optimal cut-off values were calculated using Youden's index for the anthropometric indices (sensitivity+specificity–1).[17] The index was defined for all points of the ROC curve. The maximum value of the index defined the optimal cut-off point for predicting prevalent DMT2.

Statistical analysis was performed using SPSS V.25 (IBM).

RESULT

Descriptive

A summary of the characteristics of the participants is shown in table 2. Slightly more women (54.4%) than men were included in the sample. The data show that the prevalence of DMT2 was higher among men (4.3%) compared with women (3.3%). The total prevalence for the sample was 3.7%. Men had a significantly higher

Table 2 Descriptive statistics according to sex

Characteristics	Men (n=22 830)	Women (n=27 212)	Total (n=50 042)	P value
DMT2, n (%)	975 (4.3)	901 (3.3)	1876 (3.7)	<0.001
Smoking, n (%)	5072 (22.2)	3195 (11.7)	8267 (16.5)	<0.001
Age (years)	53.6±15.6	52.8±16.3	53.1±16.1	<0.001
Weight (kg)	86.9±13.3	72.9±13.7	79.2±15.2	<0.001
Height (cm)	177.8±6.7	164.6±6.4	170.6±9.3	<0.001
HC (cm)	103.6±6.6	103.8±9.3	103.7±8.2	0.024
WC (cm)	97.4±10.5	90.3±12.8	93.6±12.3	<0.001
BMI (kg/m^2)	27.5±3.8	26.9±4.9	27.2±4.4	<0.001
<18.49, n (%)	74 (0.3)	238 (0.9)	312 (0.6)	
18.5–24.99, n (%)	5678 (25)	10 414 (45.9)	16 092 (32)	
25–29.99, n (%)	11 955 (52.4)	10 346 (37.9)	22 301 (44.4)	
>30, n (%)	5123 (22.4)	6398 (22.3)	11 521 (22.9)	
WHR	0.94±0.07	0.87±0.07	0.90±0.08	<0.001
WHtR	0.55±0.06	0.55±0.08	0.55±0.07	0.04

Results are shown as means±SD unless stated otherwise.
The comparison of characteristics between men and women (unpaired Student's t-test for numerical data, $\chi 2$ test for categorical data).
BMI, body mass index; DMT2, diabetes mellitus type 2; HC, hip circumference; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Table 3 Descriptive statistics according to participants with and without DMT2

Characteristics	Diabetes (n=1876)	Without diabetes (n=48 166)	Total (n=50 042)	P value
Smoking, n (%)	260 (13.8)	8007 (16.6)	8267 (16.5)	<0.001
Age (years)	65.4±11.8	52.7±15	53.1±16.1	<0.001
Weight (kg)	86.5±16.6	78±15.1	79.2±15.2	<0.001
Height (cm)	169±9.4	170.6±9.2	170.6±9.3	<0.001
HC (cm)	106.7±9.3	103.6±8.1	103.7±8.2	<0.001
WC (cm)	103.4±12.6	93.2±12.1	93.6±12.3	<0.001
BMI (kg/m^2)	30.2±5.0	27.1±4.3	27.2±4.4	<0.001
<18.49, n (%)	4 (0.2)	308 (0.6)	312 (0.6)	
18.5–24.99, n (%)	235 (12.5)	15 857 (32.8)	16 092 (32)	
25–29.99, n (%)	750 (40)	21 551 (44.6)	22 301 (44.4)	
>30, n (%)	887 (47.3)	10 634 (22)	11 521 (22.9)	
WHR	0.97±0.07	0.9±0.08	0.90±0.08	<0.001
WHtR	0.61±0.08	0.55±0.07	0.55±0.07	<0.001

Results are shown as means±SD unless stated otherwise.
The comparison of characteristics between participants with diabetes and without diabetes (unpaired Student's t-test for numerical data, $\chi 2$ test for categorical data).
BMI, body mass index; DMT2, diabetes mellitus type 2; HC, hip circumference; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

average age, weight, height, BMI, HC, WC, WHR and WHtR compared with women. Almost twice as many men (22.2%) were smokers compared with women (11.7%), with a total smoking prevalence of 16.5%.

Table 3 shows descriptive statistics of the participants with diabetes and without diabetes. (diabetes referring to DMT2). Average age, weight, HC, WC, BMI, WHR and WHtR were all significantly higher in the diabetes group. Of the total sample, 67.3% were either overweight or obese according to universal cut-offs for BMI and 87.3% were either obese or overweight in the diabetes group. The group without diabetes had a higher prevalence of smoking (16.6%) compared with the diabetes group (13.8%).

Associations between DMT2 and anthropometric measures

In the regression analysis, the lowest quartile was taken as the reference in the analysis. Two models were applied. The first one adjusting only for sex and the second for sex, age and smoking. Each of the four anthropometric indices showed a statistically significant increase in OR when comparing the quartiles with reference values, with the largest difference found in the highest quartiles in all models. The increase in OR across the quartiles indicates that the likelihood of having DMT2 increases for higher values of all the four anthropometric indices. The adjusted models showed a statistically significant difference in OR compared with the unadjusted model only in three cases: the OR for the highest quartile for WHR in model 1, 14.64 (11.89 to 18.02) was larger than in model 2, 8.92 (7.22 to 11.02). For WHtR, the OR for the second to highest quartile was larger in model 2, 3.22 (2.56 to 4.03) compared with the unadjusted OR, 5.22 (4.18 to 6.51) in the same quartile. Lastly, the highest quartile for WHtR had a lower OR in model 2 compared with model 1 in the same quartile (table 4).

Predictable values

WHR was the strongest predictor for DMT2 followed by WHtR, WC and BMI. The predictable value for BMI was significantly weaker than for all the other indices. The predictable value for WC was significantly weaker compared only with WHtR. The order of indices did not differ between men and women, but the predictable potential was statistically higher for women than men according to the AUC. Table 5 shows the area under the ROC curve, stratified for sex.

DISCUSSION

WHR had the strongest association with DMT2, followed by WHtR, WC and BMI. The predictable values differed between men and women, showing lower cut-offs for women for WHR and WC. The potential confounders adjusted for in the regression models (sex, age and smoking) did not affect the OR statistically except in a few cases. Notably, OR in the unadjusted model was highest for WHtR, but in the adjusted model higher for WHR, which in total placed WHR as the strongest predictor for DMT2.

While the cross-sectional design of this study does not make it possible to draw any conclusions about causality, it still provides valuable insight into the association between anthropometric indices and DMT2. The result

Table 4 OR and 95% CI of the presence of DMT2 according to quartiles of anthropometric indices

Variable	N	%	Model 1*		Model 2†	
BMI			**OR**	**95% CI**	**OR**	**95% CI**
<24.1	12235	24.5	Reference		Reference	
24.1–26.6	12597	25.2	1.76	1.45 to 2.15	1.53	1.25 to 1.86
26.7–29.5	12455	24.9	2.95	2.46 to 3.55	2.45	2.03 to 2.94
29.6+	12755	25.5	6.06	5.10 to 7.19	5.18	4.35 to 6.16
WC						
<85	11752	23.5	Reference		Reference	
85–93	11866	23.8	2.06	1.65 to 2.57	1.67	1.33 to 2.08
93–101	12918	25.8	3.5	2.84 to 4.30	2.53	2.08 to 3.13
101.1+	13476	26.9	8.91	7.33 to 10.82	6.19	5.08 to 7.54
WHR						
<0.85	12533	25.0	Reference		Reference	
0.85–0.89	12630	25.2	2.38	1.89 to 2.99	1.94	1.53 to 2.44
0.90–0 .94	12316	24.6	5.16	4.15 to 6.40	3.66	2.94 to 4.55
0.95+	12563	25.1	14.64	11.89 to 18.02	8.92	7.22 to 11.02
WHtR						
<0.50	12603	25.2	Reference		Reference	
0.50–0.53	12520	25.0	2.45	1.93 to 3.11	1.85	1.46 to 2.36
0.54–0.58	12510	25.0	4.96	3.97 to 6.19	3.22	2.56 to 4.03
0.59+	12429	24.8	12.30	9.96 to 15.2	7.19	5.80 to 8.92

Dependent variable: DMT2.
*Adjusted for sex.
†Adjusted for sex, age and smoking.
BMI, body mass index; DMT2, diabetes mellitus type 2; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

suggests that we need to be aware of the different predictive potentials of anthropometric indices for screening prevalent DMT2.

This result is in line with what previous research has concluded.[18] The prevalence of DMT2 in the sample (3.9%) is in line with the figures mentioned in the current literature.[19] The participation rate in the HUNT3 was 54.1%, this can be a source of selection bias as more people with poorer health are less prone to participate. Although, previous studies have shown that this sample is representative of the whole county of Nord-Trøndelag and the rest of Norway,[14] a high proportion of individuals were categorised as either overweight or obese in the sample (67.3%) with an average BMI of 27.2.

The AUC suggests that the predictive potential of WHR is highest in this sample, followed by WHtR, WC and BMI. The order is the same for both men and women. This result is in line with data from systematic reviews, even

Table 5 Area under the curve (AUC) with 95% CI and optimal cut-off points

AUC (men)		
Test result variables	**AUC**	**95% CI**
BMI	0.666	0.648 to 0.684
WHtR	0.723	0.707 to 0.739
WHR	0.734	0.718 to 0.750
WC	0.698	0.681 to 0.715
AUC (women)		
Test result variables	**AUC**	**95% CI**
BMI	0.713	0.696 to 0.729
WHtR	0.764	0.749 to 0.779
WHR	0.770	0.755 to 0.786
WC	0.742	0.726 to 0.757

Cut-offs according to Yoden's index indicate a trend toward lower cut-offs for women than men, for WHR and WC. Other indices show small differences between groups (table 6).
BMI, body mass index; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Table 6 Optimal cut-off points of BMI, WHtR, WHR and WC according to Youden's index

Optimal cut-offs*	Total	Men	Women
BMI	28.35	28.25	28.35
WHtR	0.57	0.58	0.57
WHR	0.93	0.96	0.90
WC	97.25	98.70	91.00

*According to Youden's index.
BMI, body mass index; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

though AUC values were higher in this study than previously reported in other studies.[10 18] All the tested anthropometric indices worked statistically significantly better for women compared with men. Whether this could be explained by the difference in anthropometry between men and women or by a potential bias is not clear. The optimal cut-off values presented in our research are similar to what previous studies have reported, for example in this study[20] the best cut-off points for Europeans were suggested to be: BMI 28.2, WC 103.4 cm and WHtR 0.607 for men. For women, the suggestion was: BMI 26.7, WC 91.4 cm and WHtR 0.584.[20]

However, the presented result indicates that for Norwegian women, the cut-offs for WHR and BMI should be higher than what other studies have suggested for European populations.[13] This could possibly be explained by the fact that Norwegian women are on average taller than central and south Europeans.[21] The presented result indicates that the difference between men and women could be small for BMI and WHtR, but that men should have a higher cut-off point than women for WC and WHR. This is in line with the current literature, even though the difference in WHR seems to be smaller for the Norwegian population than previously suggested for a general white Caucasian population.[22]

The suggested optimal cut-off estimates found based on this large population-based sample should be taken into consideration when revising national guidelines for Norway, and caution should be exercised when applying universal cut-offs for WC and BMI since these may differ from the findings in this country-specific sample. The fat distribution and the body proportion are distinct for sex and tend to change with age, which could affect the optimal cut-off points and the predictive performance of different anthropometric indices across different age groups. Future research is advised to explore this topic.

Previous research has explored the potential of combining different anthropometric indices to create an index that has a stronger correlation with disease, such as DMT2. A body shape index (ABSI, a power-law expression that normalises weight for height) was introduced in 2012 as such an index.[23] ABSI has shown to have a strong linear association with mortality. Compared with metabolic syndrome, ABSI alone was a better predictor of mortality, with the best prediction when WC was replaced by ABSI (actually by ABSI Z-score adjusting for gender and age).[24] The combination of different anthropometric indices to predict prevalent DMT2 in a Norwegian population is an interesting research topic, but this has not been within the scope of this research. Future research should explore how a new anthropometric index, such as the ABSI, correlates with prevalent DMT2 in a Norwegian population, to further understand how different indices can be used in clinical and public health practice.

To our knowledge, there are no studies that have investigated the predictive potential of anthropometric indices for DMT2 in a large population-based sample in Norway, and there is inconclusive evidence regarding the association of anthropometric indices and prevalent DMT2 in the literature. One strength of this study is the large population-based sample with standardised measurements that increase the generalisability of the results.

In the regression model, potential confounders from the available variables were applied (sex, age and smoking). The regression analysis showed that the covariates did not have a statistical impact on the association for the majority of cases, therefore they were not included in the ROC curve analysis which was only stratified for sex. This study did not include confounders like physical activity and diet which were self-reported and likely of low reliability.[25 26] Similar studies have shown that these confounders do not have a significant effect on the association.[27] The result should however be interpreted with the understanding that there are several potential confounders that have not been accounted for in the analysis such as: physical activity, diet, family history of DMT2 and socioeconomic status.

CONCLUSIONS

Our study confirms that WHtR, WHR, WC and BMI perform differently as predictive tools for prevalent DMT2 in the Norwegian population. The result contributes to clarifying which anthropometric index has the strongest association with prevalent DMT2 and suggests that WHR may be the best of the four indices we studied. We also found that these anthropometric indices detect DMT2 better in Norwegian women than men. Sex and age differences should be considered recognised when applying anthropometric indices. We have concluded that the currently most used anthropometric index, BMI, is a weaker predictor of DMT2 than WHR and WHtR. Our findings suggest that for DMT2 in a Norwegian population, body shape is more important than body size.

Contributors All authors have made a substantial contribution to the paper. AH, BMK and A-KS have all contributed to the design of the study. AH and BMK have contributed to the data analyses and AH and A-KS have contributed to the methodology and discussion of the results. All authors have revised and approved the final version of the manuscript.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval This research project was approved by the Norwegian Ethical Committee (2017/2047/REK midt). Informed consent was given from all the participants at the time of the data collection. All data used in this study were de-identified and the authors had no access to any identifier key. The consent also includes consent for publication.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. The data used in this study are owned by the research team behind the HUNT Study and is not open access. An overview of the data in HUNT can be found here: https://hunt-db.medisin.ntnu.no/hunt-db/#/survey/NT3. It is

possible to get access to the dataset used in this study, to re-examine our findings by contacting: kontakt@hunt.ntnu.no.

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