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Criterion-referenced mCAFT cut-points to identify metabolically healthy cardiorespiratory fitness among adults aged 18–69 years: An analysis of the Canadian Health Measures Survey

Emily Wolfe Phillips

Deepa P. Rao

Leonard A. Kaminsky

Grant Tomkinson
University of North Dakota, gran.tomkinson@und.edu

Robert Ross

See next page for additional authors

Authors

Emily Wolfe Phillips, Deepa P. Rao, Leonard A. Kaminsky, Grant Tomkinson, Robert Ross, and Justin J. Lang

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Authors: Emily Wolfe Phillips[1], Deepa P. Rao[1], Leonard A. Kaminsky[2], Grant R. Tomkinson[3,4], Robert Ross[5], Justin J. Lang[1]

Affiliations:

1. Centre for Surveillance and Applied Research, Public Health Agency of Canada, Ottawa, ON, Canada.

2. Fisher Institute of Health and Well-Being & Clinical Exercise Physiology Program, College of Health, Ball State University, Muncie, IN, United States

3. Department of Education, Health and Behavior Studies, University of North Dakota, Grand Forks, ND, USA.

4. Alliance for Research in Exercise, Nutrition and Activity (ARENA), School of Health Sciences, University of South Australia, Adelaide, SA, Australia

5. School of Kinesiology and Health Studies, Queens University, Kingston, ON, Canada

Corresponding Author: Justin J. Lang, Centre for Health Promotion and Chronic Disease Prevention, Public Health Agency of Canada, 785 Carling Ave, Ottawa, ON, K1A 0K9, Canada.

Email: justin.lang@canada.ca. Phone: +1 613 618 1232

List of authors:

Emily Wolfe Phillips: emily.wolfephillips@canada.ca

Deepa P. Rao: deepa.rao@canada.ca

Leonard A. Kaminsky: kaminskyla@bsu.edu

Grant R. Tomkinson: grant.tomkinson@und.edu

Robert Ross: rossr@queensu.ca

Justin J. Lang: Justin.lang@canada.ca

ABSTRACT

Objective: This study aimed to develop and validate health-related criterion-referenced cut-points for the modified Canadian Aerobic Fitness Test (mCAFT), a field-based measure to predict cardiorespiratory fitness (CRF) among adults (18–69 years). Methods: Criterion-referenced mCAFT cut-points were developed using nationally representative data from cycles 1 (2007–09) and 2 (2009–11) of the Canadian Health Measures Survey (CHMS). Receiver operating characteristic curves were used to identify age- and sex-specific cut-points for measured waist circumference, blood pressure, and high-density lipoprotein. Cut-points were validated against metabolic syndrome using a fasted sub-sample (n=1,093) from cycle 5 (2016–17). Results: 4,967 participants (50% women) were retained for the main analyses. The mCAFT cut-points ranged from 28 to 43 mL•kg–1•min–1 (AUC: 0.60-0.87) among men, and 23 to 37 mL•kg–1•min–1 (AUC: 0.61-0.86) among women. The likelihood of meeting the new mCAFT cut-points decreased with an increase in the presence of metabolic risk factors. In total, 54% (95%CI: 42 to 67%) of Canadian adults met the new mCAFT cut-points in 2016–17. Conclusion: This study developed and validated the first health-related criterion-referenced mCAFT cut-points for metabolic health among Canadian adults aged 18–69 years. These mCAFT cut-points may be useful in health surveillance, clinical, and public health settings.

Novelty bullets

- We developed and validated new criterion-referenced cut-points for the modified Canadian Aerobic Fitness Test to help identify adults at potential risk of poor metabolic health.
- These new cut-points could help support national health surveillance efforts.

Keywords: Cardiorespiratory fitness, adults, metabolic syndrome, health, surveillance, fitness, aerobic evaluation

INTRODUCTION

Cardiorespiratory fitness (CRF) represents the ability of the heart, lungs, and muscles to deliver oxygen to support muscle movement during physical activity (Ross et al. 2016). CRF is partly determined by genetics (30–50%), and primarily modified by physical activity (Bouchard and Shephard 1994). CRF is considered an important modifiable trait among adults that is negatively associated with a range of chronic health conditions (e.g., cardiovascular diseases, diabetes), including metabolic syndrome (Ross et al. 2016; Ford and Li 2008; Katzmarzyk et al. 2005; Kelley et al. 2018). Further, higher CRF is associated with lower all-cause mortality risk (Kodama et al. 2009). Research also suggests that the addition of CRF to traditional risk scores, such as the Framingham, substantially improves the net reclassification of patients in clinical settings (Ross et al. 2016). For these reasons, the American Heart Association has recommended the inclusion of CRF as a clinical vital sign that should be measured in clinical and public health settings (Ross et al. 2016).

CRF can be estimated indirectly using non-exercise equations (Nes et al. 2011; Nes et al. 2014), questionnaires (Merellano-Navarro et al. 2017), submaximal exercise tests (e.g., 6-minute walk test; Enright 2003), or maximal exercise tests (e.g., treadmill running test; Myers et al. 1991) with or without gas analysis. Although lab-based gas analyzed exercise tests with maximal effort are the gold standard assessment of CRF, they are costly and time-consuming making them difficult to implement in population-based surveillance. In Canada, nationally representative estimates for CRF are predicted using the modified Canadian Aerobic Fitness Test (mCAFT) (Weller et al. 1993; Weller et al. 1995), a submaximal test collected through a national health survey (Canadian Health Measures Survey [CHMS]).

To help establish CRF as a clinical and public health vital sign it is important to identify the minimal CRF values (i.e., $\dot{V}O_{2max}$) associated with low risk for poor health outcomes (e.g., chronic diseases, mortality risk), known as clinical cut-points or thresholds. The two most common methods used to establish cut-points include normative- and criterion-referenced (Lang et al 2019). Whereas several normative-based cut-points have been proposed (Riebe et al. 2018; CSEP 2013; Hoffmann et al. 2019), a limitation of such an approach is that normative cut-points are generally not linked to a health-related outcome. There are currently no known health-related criterion-referenced cut-points for CRF among adults. The closest health-related cut-points (i.e., linked to risk of mortality and cardiovascular events) for the general population were proposed through a comprehensive meta-analysis that suggested $\dot{V}O_{2max}$ values for men and women aged 40–60 years should be greater than 25 to 32 mL•kg^{-1}•min^{-1} and 18 to 25 mL•kg^{-1}•min^{-1}, respectively, depending on age groups (Kodama et al. 2009).

This paper was organized into two phases that correspond to the datasets that were analyzed. The objective of phase one was to establish age- and sex-specific health-related criterion-referenced cut-points for the mCAFT among Canadian adults aged 18–69 years using CHMS data from 2007–11 (cycles 1 and 2). The objective of phase two was to validate the established mCAFT cut-points against metabolic syndrome in an independent sub-sample of fasted participants from the CHMS, 2016–17 (cycle 5). The secondary objective of phase two was to calculate the prevalence of Canadian adults that met the new mCAFT cut-points in an independent sub-sample of non-fasted participants from the CHMS, 2016–17 (cycle 5).

MATERIALS AND METHODS

Participants

To establish age- and sex-specific mCAFT cut-points (phase 1) we obtained data from 4,967 participants aged 18–69 years (50.4% women; mean age, 95% confidence interval: 40.5 years [40.0, 41.0]) from cycles 1 (2007–09) and cycle 2 (2009–11) of the CHMS. As part of phase two, we analyzed CHMS cycle 5 data (2016-17) in two sub-samples: fasted and non-fasted. Within each dwelling, participants were randomly assigned to the fasted or non-fasted sample. The sampling fractions were adjusted to obtain approximately half of the sample fasted (Statistics Canada 2013a, 2013b). To validate the new cut-points, we analyzed the subsample of 1,093 fasted participants from cycle 5 (51.0% women; mean age, 95% confidence interval: 43.0 years [42.0, 44.1]). To calculate the prevalence of Canadian adults meeting the new mCAFT cut-points, we analyzed a subsample of 1,094 non-fasted participants from cycle 5(50.3% women; mean age, 95% confidence interval: 40.7 years [39.1, 42.2]). Details on sampling, data collection, and the measures included in the CHMS are described in detail elsewhere (Statistics Canada 2013a, 2013b; Tremblay et al. 207; Tremblay et al. 2010). Briefly, the CHMS is a nationally representative, cross-sectional survey used to collect objectively measured health data from Canadians aged 3–79 years. Approximately 96% of Canadians are represented in the CHMS, with those from the three territories, Aboriginal settlements, members of the Canadian Forces, institutionalized individuals, and those living in certain rural areas excluded from the survey. Data collection for the CHMS took place in two steps: first, participants provided demographic and self-reported information during an interview conducted at the participant's household; next, participants attended a mobile examination centre to collect direct health measures. The overall response rate for cycles 1 and 2 was 54% and 49% for cycle 5 (Statistics Canada 2013a, 2013b, 2019). Bootstrap and sample weights were used to account for the complex survey design and non-response bias. The CHMS was approved by the Health Canada

Research Ethics Board (Day et al. 2007). All participants provided written, informed consent prior to participating in the survey.

Modified Canadian Aerobic Fitness Test

Trained health specialists assessed CRF using the mCAFT — a progressive submaximal step test. The mCAFT was assessed following the Canadian Physical Activity, Fitness and Lifestyle Approach protocol (CSEP 2003). Details on the mCAFT can be found elsewhere (Craig et al. 2012). Briefly, participants followed an age- and sex-specific cadence that increased every three minutes. The test was terminated when a participant's heart rate reached 85% of their age-predicted maximal heart rate (220 – age) at the end of the stage (Fox and Naughton 1972). Participants were also able to terminate the test if they could not complete a full 3-minute stage. The mCAFT has very strong criterion validity against gas-analyzed $\dot{V}O_{2max}$ (r=0.88) in Canadians aged 15–69 years (Weller et al. 1993, 1995). Participant's $\dot{V}O_{2max}$ (mL•kg^{-1}•min^{-1}) was estimated using the following prediction equation:

$$\text{Predicted } \dot{V}O_{2max} = 17.2 + (1.29 * \dot{V}O_2) - (0.09 * \text{mass}) - (0.18 * \text{age})$$

where $\dot{V}O_2$ *is the oxygen cost in mL•kg^{-1}•min^{-1}of the final completed stage, mass is in kilograms, and age is age in years at last birthday* (CSEP 2003; Weller 1989).

Phase one, establishing criterion-referenced cut-points

Three criterion health measures (waist circumference, blood pressure, and high-density lipoprotein [HDL] cholesterol) were assessed by trained health specialists. The criterion health measures used to calculate the mCAFT cut-points were obtained from cycles 1 and 2 (2007–11) of the CHMS. *Waist circumference* was measured at the midpoint between the lowest floating rib and the top of the iliac crest following the World Health Organization protocol (World Health

Organization 2008). Waist circumference thresholds to identify abdominal obesity were based on the values recommended as part of the harmonized metabolic syndrome statement that recommends population or ethnicity specific thresholds (Alberti et al. 2008). *Systolic and diastolic blood pressure* were measured using the CHMS protocol which allows for five minutes of quiet rest followed by six measurements at 1-minute intervals using an automated oscillometer 2(BpTRU^{TM} BPM-300, BpTRU^{TM} Medical Devices Ltd., Coquitlam, British Columbia) (Paradis et al. 2010; Joffres et al. 2013; Wilkins et al. 2010). The mean resting blood pressure was calculated from the final five measurements. Blood pressure was classified as high following the harmonized metabolic syndrome statement (systolic ≥130 and/or diastolic ≥85 mmHg) (Alberti et al. 2008). Self-reported anti-hypertension medication was also used to classify individuals with elevated blood pressure. *HDL cholesterol* was measured in serum from non-fasted blood samples. Low HDL cholesterol was classified following the harmonized metabolic syndrome statement (<1.0 mmol/L for men and <1.3 mmol/L for women) ((Alberti et al. 2008). Participants who self-reported using bile acid sequestrants were also classified as having low HDL cholesterol. Blood samples were collected by certified phlebotomists and analyzed at the Health Canada laboratory following standardized procedures (Bryan et al. 2007).

Phase two, validation against metabolic syndrome

A sub-sample of participants who took part in cycle 5 (2016–17) of the CHMS were randomly flagged and asked to fast for 10 hours prior to data collection (Statistics Canada 2019). This sub-sample participated in the full CHMS measurement protocol in addition to providing fasting blood samples to measure triglycerides and glucose levels. Certified phlebotomists collected all blood samples which were analyzed at the Health Canada laboratory following standard procedures (Bryan et al. 2007). More details about the sampling, storage, and analyses of bio-specimens from the CHMS are reported elsewhere (Bryan et al. 2007). Metabolic syndrome was defined using the harmonized metabolic syndrome statement which was operationalized as meeting at least three of the following risk factors: elevated waist circumference (using population or ethnicity specific thresholds); elevated triglycerides (≥1.7 mmol/L); low HDL (<1.0 mmol/L for men and <1.3 mmol/L for women); elevated blood pressure; elevated fasting glucose (≥5.5 mmol/L) (Alberti et al. 2008). Self-reported medication use for problematic triglycerides, cholesterol, blood pressure, and/or glucose was also used to classify individuals as having the related risk factor (Alberti et al. 2008). The fasted sub-sample was used to cross-validate the established mCAFT cut-points by describing the ability to discriminate individuals across stratums of metabolic syndrome risk factors.

Phase two, prevalence meeting the new mCAFT cut-points

A non-fasted subsample of from cycle 5 the CHMS (2016–17) was used to calculate the prevalence of Canadian adults meeting the new mCAFT cut points. All participants with a valid mCAFT score were included in the prevalence analysis.

Statistical analyses

Analyses were conducted using the Statistical Analysis System Enterprise Guide (SAS EG; version 5.1). Statistical significance was set at $p<0.05$. Descriptive statistics were calculated for all study variables as means or proportions with 95% confidence intervals.

Phase one analysis. Receiver operating characteristic (ROC) curve analyses were used to identify mCAFT cut-points to help detect individuals at increased metabolic risk across age- and sex-specific groups. Metabolic risk was operationalized using waist circumference, blood pressure, and HDL cholesterol. ROC curve values were plotted as sensitivity and specificity for each potential cut-point value. Sensitivity (or true positive rate) represents the proportion of the sample correctly identified as metabolically unhealthy, and specificity (or true negative rate) represents the proportion of the sample correctly identified as metabolically healthy. Cut-points that optimized both sensitivity and specificity were selected (i.e., Youden's J) (Fluss et al. 2005). The area under the curve (AUC) was calculated as a summary statistic that represents the discriminatory ability of the mCAFT. An AUC value of 1 represents a perfect discriminatory ability, a value of 0.5 represents no discriminatory ability, and AUC values of 0.55–0.62, 0.63–0.71 and >0.71 represent weak, moderate, and strong effect sizes, respectively (Rice et al. 2005). ROC curve analyses were conducted for waist circumference, blood pressure, and HDL cholesterol, separately for each sex and the three age groups (18–34, 35–54, and 55–69). The mean mCAFT cut-point across all three measures was selected as the recommended cut-points for each age and sex specific group. More details on ROC curves using complex survey data are provided elsewhere (Lang et al. 2020; Agnelli 2014).

Phase two, validation analysis. Stratum-specific likelihood ratios were calculated to evaluate the accuracy of the new mCAFT cut-points in classifying individuals across metabolic syndrome risk factor strata (0–2 indicators, 3 indicators, and 4–5 indicators) (Peirce et al. 1993; Schmitz et al. 2000). Within each metabolic syndrome category (stratum), the ratio of individuals meeting versus not meeting the new mCAFT cut-points were calculated (Peirce et al. 1993). A stratum-specific likelihood ratio of ≥5 suggests that individuals within a stratum are highly unlikely to meet the new cut-points, whereas a stratum-specific likelihood ratio of <0.1 indicates that individuals in a stratum are highly likely to meet the cut-point (Feng et al. 2009). It was anticipated that the stratum-specific likelihood ratios would increase with an increase in the number of metabolic syndrome risk factors across strata.

Phase two, prevalence analysis. Following the validation analyses, the prevalence of Canadian adults meeting the new mCAFT cut-points in 2016–17 (CHMS cycle 5) was calculated using survey and bootstrap weights.

RESULTS

Descriptive statistics for the phase one sample (cycles 1 and 2), the phase two validation sub-sample (cycle 5 fasted sub-sample) and the phase two prevalence sub-sample (cycle 5 non-fasted sample) are presented in Table 1. Among the phase one sample (2007–11), mean CRF was 16% higher among men (39.2 mL•kg^{-1}•min^{-1}) than women (33.7 mL•kg^{-1}•min^{-1}). Among men and women, respectively, approximately 27% and 36% had an elevated waist circumference, 23% and 31% had low HDL, and 18% and 9% had elevated blood pressure. The values for the phase one sample were not substantially different from the values in the phase two sub-samples.

The ROC curve generated mCAFT cut-points, sensitivity, specificity, positive and negative predictive values for each age by sex group are presented in Table 2, representing phase one of this study. The average mCAFT cut-points associated with high metabolic risk were 42.7 mL•kg^{-1}•min^{-1} for younger men (18–34 years), 38.5 mL•kg^{-1}•min^{-1} for middle-aged men (35–54 years), and 27.9 mL•kg^{-1}•min^{-1} for older men (55–69 years). Among women, the mCAFT cut-points associated with metabolic syndrome were 37.0 mL•kg^{-1}•min^{-1} for younger women (18–34 years), 33.6 mL•kg^{-1}•min^{-1} for middle-aged women (35–54 years), and 23.2 mL•kg^{-1}•min^{-1} for older women (55–69 years). ROC curves including AUC values across age and sex groups are presented in Figure 1 for men and Figure 2 for women. The AUC values ranged from 0.60 to 0.87 and 0.61 to 0.86 for men and women, respectively. All of the ROC curves demonstrated acceptable AUC values (all values >0.6), representing moderate predictive power for the mCAFT to discriminate those with or without an existing metabolic risk factor.

The stratum-specific likelihood ratios calculated in the validation sub-sample (phase two) ranged from 0.75 to 12.59 and increased with each subsequent increase in metabolic syndrome stratum (Table 3). The stratum-specific likelihood ratios were <1 for adults with 0–2 existing metabolic syndrome risk factors (indicators). For individuals with 3 existing metabolic syndrome risk factors (indicators) stratum-specific likelihood ratios values were 3.0 and 4.5 for men and women, respectively. Among individuals with 4–5 existing metabolic syndrome risk factors (indicators), the stratum-specific likelihood ratios were 6.2 and 12.5 for men and women, respectively.

In phase two, 54% (95%CI: 43 to 65%) of men and women met the new mCAFT cut-points, with the prevalence of men being slightly higher than women (54% [95%CI: 42 to 67%]). Among men, 74% (95%CI: 61 to 86%) of younger, 41% (95%CI: 29 to 53%) of middle-aged, and 48% (95%CI: 33 to 63%) of older men met the mCAFT cut-points. Among women, 61% (95%CI: 41 to 80%) of younger, 47% (95%CI: 33 to 60%) of middle-aged, and 56% (95%CI: 37 to 74%) of older women met the mCAFT cut-points (Supplementary Figure S1).

DISCUSSION

This study represents a large effort to produce the first data driven age- and sex-specific mCAFT cut-points to help identify individuals at risk of poor metabolic health. To our knowledge, these are the first cut-points to be validated against objectively measured metabolic syndrome among adults. They also help support a growing body of literature on criterion-referenced cut-points for healthy CRF that have largely been focused in paediatric populations (Lang et al. 2019). The new mCAFT cut-points ranged from 27.9 mL•kg^{-1}•min^{-1} to 42.7 mL•kg^{-1}•min^{-1} among men, and from 23.2 mL•kg^{-1}•min^{-1} to 37.0 mL•kg^{-1}•min^{-1} among women. These cut-points are higher than values reported elsewhere using different CRF measures (discussed in detail below) (Kodama et al. 2009). Individuals were increasingly less likely to meet the new mCAFT cut-points as the number of existing metabolic syndrome risk factors increased. Women were almost twice as likely as men to not meet the new cut-points when ≥4 risk factors were present. AUC values were highest for waist circumference compared to HDL and blood pressure, which suggests that the mCAFT is better at discriminating individuals with high waist circumference.

To our knowledge, there are no published health-related criterion-referenced mCAFT cut-points for adults, although normative based cut-points using a quintile framework have been proposed for the mCAFT by the Canadian Society for Exercise Physiology (CSEP 2013). The CSEP Health Benefit Rating Zones have been used categorize CRF as poor, fair, good, very good, or excellent based on age- and sex-specific centile distributions (CSEP 2013; Shields et al. 2010). The new mCAFT cut-points fall within the poor, fair, or good zones with no apparent sex- or age-specific patterns emerging. The CSEP Health Benefit Rating Zones were not tied to a health-related outcome, suggesting that an individual's mCAFT score may be considered as poor or fair based on the Health Benefit Rating Zones despite being above the new health-related CRF cut-points.

Our mCAFT cut-points are higher across all age and sex groups when compared to those proposed by Kodama et al (2009). These differences may be partially explained by the variety of CRF assessments included in the meta-analysis (e.g., treadmill, cycle ergometer) and the inclusion of maximal and submaximal working capacity tests. Further, Kaminsky et al (2015), developed referenced-based CRF cut-points using cardiopulmonary exercise testing (a direct measure of $\dot{V}O_{2\ max}$) in adults from the United States. Reference values are presented for men and women in 10-year age groups (e.g., 20–29, 30–39 year olds etc.), whereas we presented our results by younger (18–34 years), middle-aged (35–54 years), and older (55–69 years) age groups. Despite differences in age groups and CRF fitness testing methods, recommended values were similar across different age and sex groups. The mCAFT cut-points were approximately 4.7 to 5.7 mL•kg^{-1}•min^{-1} lower among women compared to men, which is similar to Kaminsky et al (2015).

As anticipated, our mCAFT cut-points decreased with age. For example, the cut-points decreased by 10% (men) and 9% (women) between young and middle adulthood, and by 28% (men) and 31% (women) between middle and older adulthood. Although evidence supports the declines in CRF with age, the age-related change in criterion-referenced CRF cut-points for metabolic risk has been sparsely investigated in the literature and represents an area of future research (Kminsky et al. 2015).

Our validation analyses support the notion that those who have metabolic syndrome are more likely to not meet the new mCAFT cut-points. The likelihood of not meeting the new cut-points was much higher for those with ≥4 metabolic risk factors present, compared to those with ≤3 metabolic risk factors. Among those with ≥4 existing risk factors, women were almost twice as likely to not meet the new cut-points. Given that the current guidelines for the classification of metabolic syndrome are the presence of ≥3 risk factors, there may be value in assessing metabolic syndrome in relation to the mCAFT based on the number and type of indicators present (Alberti et al. 2009).

Among individuals who participated in cycle 5 (2016–17) of the CHMS, 54% of Canadian adults met the mCAFT cut-points. These values are low considering the fact that only 15% and 19% of men and women, respectively, were classified as having metabolic syndrome in 2016–17. This suggests that our mCAFT cut-points are conservative and should not be used to diagnose metabolic syndrome. Rather, these cut-points should be used to screen individuals at increased risk of metabolic syndrome and in need of a more thorough examination. This cost-effective, non-invasive approach could help save considerable time in clinical settings. While the proportion of adults meeting the mCAFT cut-points decreased as expected from young to middle adulthood, the proportion increased from middle to older adulthood. This was unexpected given the results from the analytical sample. There are several possible explanations for this result, including a healthy volunteer effect where individuals who were healthy were potentially more likely to participate in the survey, an effect that may have been more evident in older adults. There also may have been a selection bias as a result of rigorous inclusion/exclusion criteria. Conversely, it could be that the mCAFT cut-points for older adults are easier to attain and result in slightly higher proportions meeting the cut-points in comparison with their middle-aged counterparts.

Strengths and limitations

Strengths of the present study include a large, nationally representative sample, the use of an objective measure to estimate CRF (mCAFT), and directly-measured metabolic syndrome risk factors classified using the harmonized statement on metabolic syndrome (Alberti et al. 2008). The use of ROC curves to derive health-related criterion-referenced cut-points and the inclusion of an independent validation sub-sample are also strengths. Other strengths include the use of survey and bootstrap weights to account for non-response and the complex survey design.

Despite these strengths, there were several limitations. For instance, we used cross-sectional data which precludes causal relationships. As CRF data were collected using the mCAFT, cut-points should not be applied to other measures of CRF or other populations without proper investigation. Given the higher respondent burden to collect fasting blood work, glucose and triglyceride levels are not available for the entire CHMS sample, hindering the ability to use all five indicators of metabolic syndrome in the initial identification of the cut-points. The 95% confidence intervals were not calculated for the AUC, sensitivity, and specificity as the survey and bootstrap weights could not be integrated in the ROC curve calculations. The strict inclusion criteria for participation in the mCAFT may have biased our results towards a healthier and fitter sample by excluding individuals based the Physical Activity Readiness Questionnaire (PAR-Q) and/or other exclusion criteria (e.g., elevated resting heart rate or blood pressure values, difficulty breathing at rest) (Statistics Canada 2013b). Previous studies have showed that those excluded from the mCAFT in the CHMS typically had a higher body mass index when compared with those who were included in the mCAFT (Shields et al. 2010). The health-related nature of the study may have also created a higher rate of non-response for those who were unhealthy. This scenario was partially tested by comparing body mass index values between the CHMS and the Canadian Community Health Survey (a general health survey), with results indicating a negligible difference between the surveys (Shields et al. 2010). This suggested that, at least for body mass index, the nature of the CHMS did not have an impact on survey estimates.

Conclusions and future directions

This study developed and validated the first health-related criterion-referenced mCAFT cut-points for metabolic health among Canadian adults aged 18–69 years. These findings can help support the classification of potentially at-risk individuals using the mCAFT in both clinical and public health settings. From a practical perspective, implementing field-based measurements of CRF, such as the mCAFT, is often more feasible and cost-effective when compared to assessing biomarkers through blood samples. These findings can also help advance CRF as a clinical vital sign, as proposed by the American Heart Association (Ross et al. 2016). Future research should validate the mCAFT cut-points using other field-based or lab-based measures of CRF to increase their clinical, health surveillance, and public health applicability.

Conflict of interest: The authors have no conflicts of interest to report.

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Table 1. Descriptive statistics for Canadian adults aged 18–69 years

Characteristics Mean/% (95%CI)	**Phase one sample** **2007–11, *n*=4,967**		**Phase two validation sample** **2016–17, *n*=1,093**		**Phase two prevalence sample** **2016–17, *n*=1,094**	
	Men	**Women**	**Men**	**Women**	**Men**	**Women**
Sex, %	50.4 (49.3, 51.6)	49.7 (48.4, 50.7)	49.0 (45.2, 52.7)	51.0 (47.3, 54.8)	49.7 (45.0, 54.4)	50.3 (45.6, 55.0)
Age, %						
18–34 years	38.0 (35.3, 40.7)	35.4 (33.2, 37.6)	31.5 (27.1, 36.0)	33.8 (26.1, 41.4)	36.6 (29.3, 43.9)	41.4 (34.6, 48.2)
35–54 years	45.8 (42.7, 49.0)	45.8 (43.2, 48.4)	45.8 (37.6, 54.0)	38.8 (30.9, 46.7)	42.6 (34.7, 50.5)	40.2 (33.0, 47.4)
55–69 years	16.2 (14.1, 18.3)	18.8 (16.6, 21.1)	22.7 (16.1, 29.3)	27.4 (22.7, 32.1)	20.8 (15.9, 25.7)	18.4 (12.9, 23.9)
Household education, %						
Less than college	17.9 (14.8, 21.0)	19.2 (15.0, 23.3)	29.2 (20.2, 38.4)	24.2 (18.3, 30.1)	22.1 (13.8, 30.4)	20.2 (14.1, 26.3)
College	33.9 (27.8, 40.0)	37.2 (32.8, 41.6)	22.6 (17.4, 27.8)	21.5 (14.0, 28.9)	23.1 (13.5, 32.7)	30.5 (22.9, 38.0)
University	48.2 (40.3, 56.0)	43.6 (37.6, 49.7)	48.1 (39.1, 57.1)	54.3 (45.4, 63.1)	54.8 (47.6, 62.0)	49.4 (37.2, 59.5)
mCAFT CRF,						
$\dot{V}O_{2max}$, mL•kg–1•min–1	39.2 (38.5, 40.0)	33.7 (33.3, 34.2)	36.6 (35.3, 38.1)	31.3 (29.9, 32.7)	38.1 (36.9, 39.3)	33.7 (32.5, 35.0)
Waist circumference, cm						
Waist circumference	93.1 (92.0, 94.3)	84.3 (83.0, 85.6)	93.9 (90.8, 97.0)	88.2 (85.2, 91.2)	94.7 (92.6, 96.8)	85.4 (82.4, 88.4)
Elevated waist circumference, %	27.2 (23.4, 30.9)	35.6 (31.9, 39.3)	23.6 (16.4, 30.1)	45.3 (38.5, 52.2)	29.7 (22.4, 37.0)	33.4 (24.4, 42.4)
HDL, mmol/L						
HDL	1.2 (1.2, 1.3)	1.5 (1.5, 1.6)	1.3 (1.2, 1.3)	1.7 (1.6, 1.8)	1.2 (1.2, 1.3)	1.6 (1.6, 1.7)
Reduced HDL, %	22.9 (18.5, 27.4)	31.1 (25.8, 36.4)	19.7 (13.4, 26.0)	22.6 (17.0, 28.2)	28.9 (21.3, 36.5)	27.1 (21.4, 32.9)
Systolic Blood Pressure, mmHg						
Systolic blood pressure	112.3 (111.2, 113.4)	105.8 (104.7, 106.9)	112.0 (110.7, 113.3)	110.0 (107.0, 112.9)	111.9 (110.5, 113.3)	107.2 (105.3, 109.1)
Diastolic blood pressure	73.4 (72.6, 74.2)	68.5 (67.8, 69.2)	73.3 (72.4, 74.2)	71.0 (69.7, 72.3)	72.2 (70.7, 73.7)	69.8 (68.4, 71.3)
Elevated blood pressure, %	17.5 (14.3, 20.7)	9.1 (7.0, 11.2)	20.9 (17.1, 24.6)	15.7 (8.4, 23.1)	16.2 (10.0, 22.4)	12.8 (7.9, 17.6)
Triglycerides, mmol/L						
Triglycerides	-	-	1.4 (1.3, 1.5)	1.2 (1.1, 1.3)	-	-
Elevated triglycerides, %	-	-	24.2 (17.4, 30.9)	16.3 (11.5, 21.0)	-	-
Fasting glucose, mmol/L						
Fasting glucose	-	-	5.5 (5.4, 5.6)	5.2 (5.0, 5.4)	-	-
Elevated fasting glucose, %	-	-	28.8 (23.6, 34.1)	15.8 (8.5, 23.1)	-	-
Metabolic syndrome, %						
Metabolic syndrome	-	-	14.6 (9.6, 19.5)	18.1 (11.2, 25.1)	-	-

Note: 95% CI=95% confidence interval; CRF=cardiorespiratory fitness; mCAFT= modified Canadian Aerobic Fitness Test; $\dot{V}O_{2max}$=maximum oxygen uptake in mL/kg/min; HDL= high density lipoprotein; mmol/L= millimoles per litre; mmHg=millimeters of mercury.

Source: 2007-2009 and 2009-2011 (cycles 1 and 2) of the Canadian Health Measures Survey, combined; cycle 5 (2016-2017) of the Canadian Health Measures Survey (Statistics Canada 2013a; Statistics Canada 2013b; Statistics Canada 2019).

Table 2. Receiver operating characteristic curves to establish optimal outcome-specific mCAFT cut-points for young, middle-aged, and older adults. Mean values represent the recommended mCAFT cut-point for each age group.

	$\dot{V}O_{2\,max}$ (mL•kg⁻¹•min⁻¹)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Younger men (18–34 years)					
Elevated WC	42.0	78.7	83.1	45.9	95.6
Elevated BP	44.2	77.3	60.8	100.0	97.9
Low HDL	41.8	44.3	80.8	38.1	84.4
Mean $\dot{V}O_{2\,max}$ (SD)	42.7 (1.3)				
Middle-aged men (35–54 years)					
Elevated WC	39.3	82.4	62.3	51.0	88.1
Elevated BP	38.9	67.6	54.4	23.3	89.2
Low HDL	37.4	58.4	63.6	34.2	82.6
Mean $\dot{V}O_{2\,max}$ (SD)	38.5 (1.0)				
Older men (55–69 years)					
Elevated WC	26.5	61.8	81.4	66.2	78.4
Elevated BP	29.7	74.5	45.7	44.7	75.3
Low HDL	27.6	60.5	59.9	26.5	86.3
Mean $\dot{V}O_{2\,max}$ (SD)	27.9 (1.6)				
Young women (18–34 years					
Elevated WC	37.1	73.9	82.0	58.4	90.2
Elevated BP	36.6	70.6	73.6	4.9	99.2
Low HDL	37.3	47.6	71.4	46.7	72.1
Mean $\dot{V}O_{2\,max}$ (SD)	37.0 (0.4)				
Middle-aged women (35–54 years)					
Elevated WC	34.2	82.2	62.7	57.5	85.1
Elevated BP	31.4	61.9	68.8	15.9	95.0
Low HDL	35.1	72.6	43.9	38.3	77.0
Mean $\dot{V}O_{2\,max}$ (SD)	33.6 (1.9)				
Older women (55–69 years)					
Elevated WC	23.1	66.4	81.3	78.2	70.5
Elevated BP	23.7	66.2	58.1	38.2	81.4

Low HDL	22.7	52.9	66.7	32.3	82.5
Mean $\dot{V}O_{2\ max}$ (SD)	23.2 (0.5)				

WC=waist circumference; BP=blood pressure; HDL=high density lipoprotein; SD=standard deviation; PPV = positive predictive value; NPV = negative predictive value

Data source: 2007-2009 and 2009-2011 (cycles 1 and 2) of the Canadian Health Measures Survey, combined (Statistics Canada 2013a; Statistics Canada 2013b).

Table 3. Stratum-specific likelihood ratios used to validate the established mCAFT cut-points across strata (categories) of metabolic syndrome risk factors for men and women, separately.

	0–2 risk factors		**3 risk factors**		**4–5 risk factors**	
	SSLR	**95% CI**	**SSLR**	**95% CI**	**SSLR**	**95% CI**
Men	0.75	(0.69, 0.82)	3.26	(1.78, 5.97)	6.64	(2.65, 16.39)
Women	0.79	(0.73, 0.84)	4.26	(2.04, 8.91)	12.59	(3.04, 52.07)

Note: *Three or more risk factors present was used to identify individuals with metabolic syndrome. SSLR = stratum-specific likelihood ratios; 95% CI=95% confidence interval*

Data source: cycle 5 (2016-2017) of the Canadian Health Measures Survey (Statistics Canada 2019).

FIGURE CAPTIONS

Figure 1. Receiver Operating Characteristic curves plotting sensitivity and 1–specificity for Canadian men by age group for blood pressure, high-density lipoprotein, and waist circumference. Data source: Canadian Health Measures Survey cycles 1 and 2 (2007–11). BP=blood pressure; HDL=high-density lipoprotein; WC=waist circumference; AUC=area under the curve (Statistics Canada 2013a; Statistics Canada 2013b)

Figure 2. Receiver Operating Characteristic curves plotting sensitivity and 1–specificity for Canadian women by age group for blood pressure, high-density lipoprotein, and waist circumference. Data source: Canadian Health Measures Survey cycles 1 and 2 (2007–11). BP=blood pressure; HDL=high-density lipoprotein; WC=waist circumference; AUC=area under the curve (Statistics Canada 2013a; Statistics Canada 2013b)

Figure 1

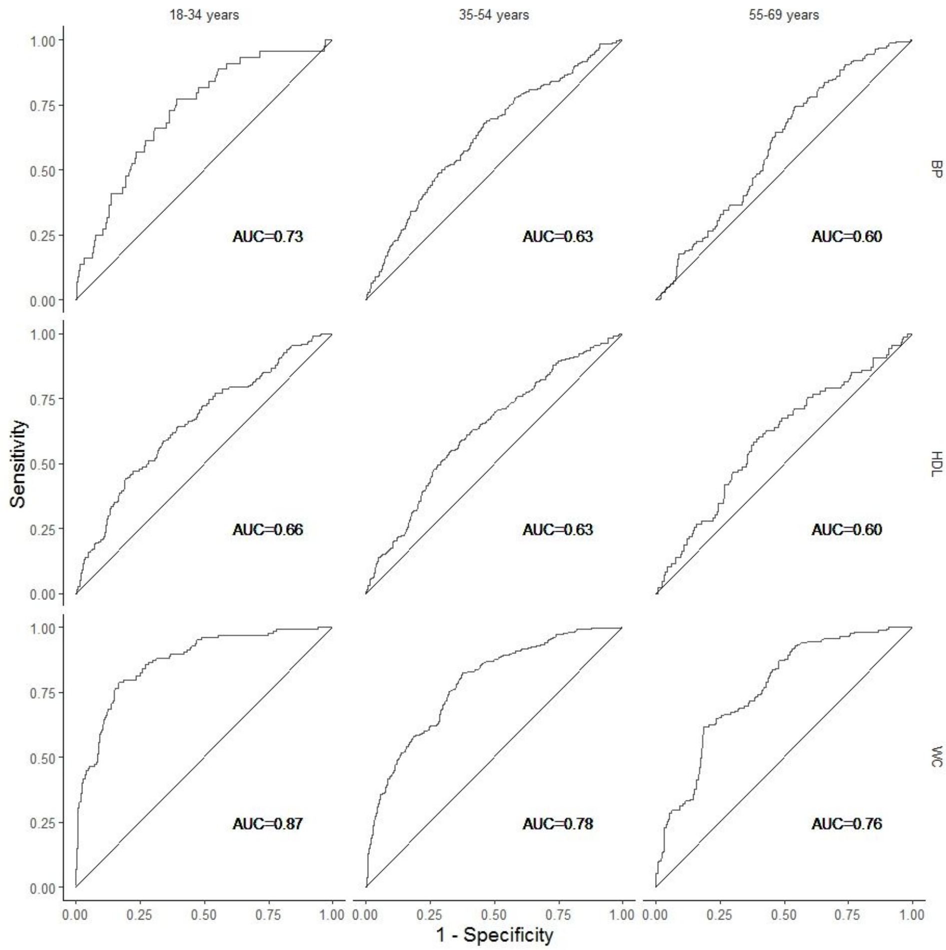
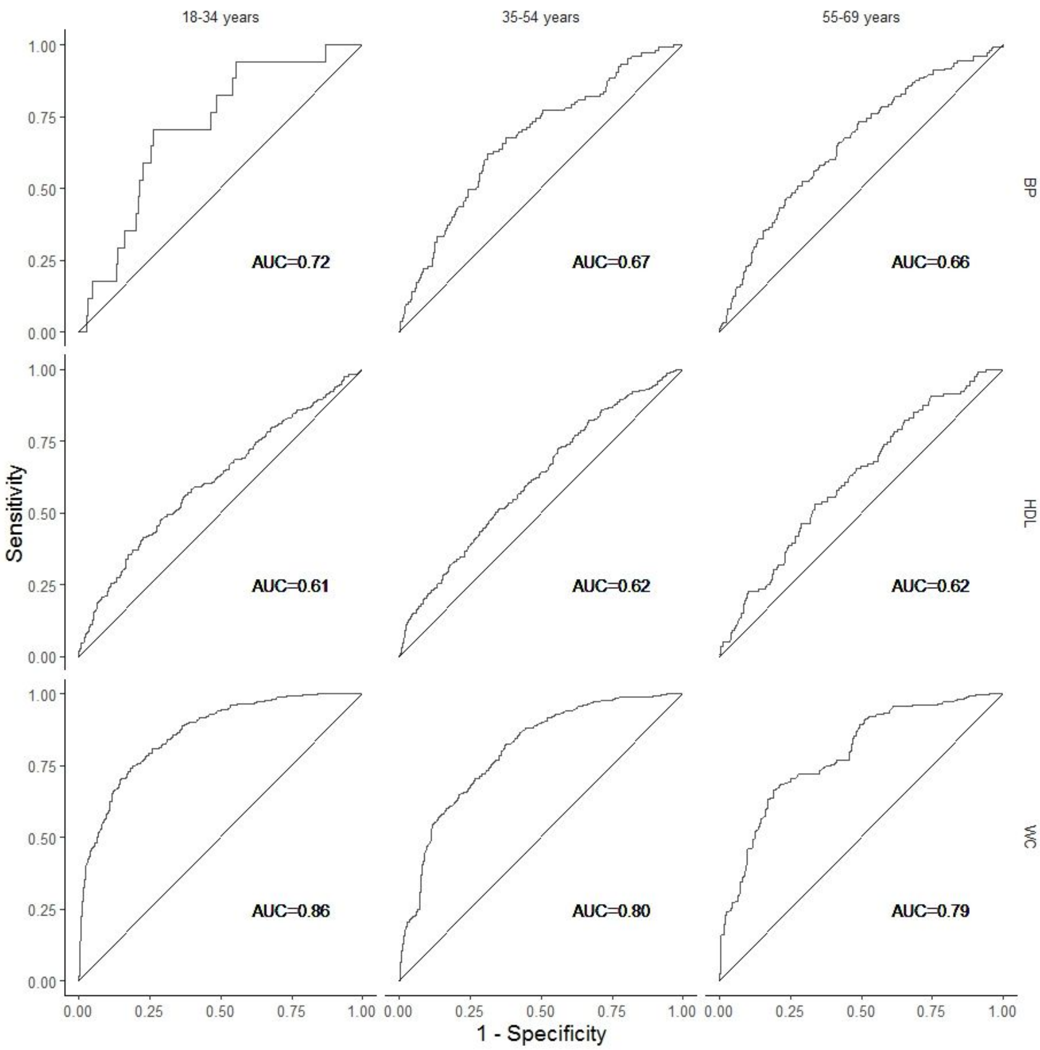

18-34 years
35-54 years
55-69 years
BP
HDL
WC
Sensitivity
1 - Specificity
AUC=0.73
AUC=0.63
AUC=0.60
AUC=0.66
AUC=0.63
AUC=0.60
AUC=0.87
AUC=0.78
AUC=0.76
0.00
0.25
0.50
0.75
1.00

Figure 2


18-34 years
35-54 years
55-69 years
BP
HDL
WC
Sensitivity
1 - Specificity
AUC=0.72
AUC=0.67
AUC=0.66
AUC=0.61
AUC=0.62
AUC=0.62
AUC=0.86
AUC=0.80
AUC=0.79
0.00
0.25
0.50
0.75
1.00