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Development of the WAIS-III estimate of premorbid ability for Canadians (EPAC)

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Abstract

This study developed regression algorithms for estimating IQ scores using the Canadian WAIS-III norms. Participants were the Canadian WAIS-III standardization sample ($n = 1105$). The sample was randomly divided into two groups (Development and Validation groups). The Development group was used to generate 12 regression algorithms for FSIQ and three algorithms each for VIQ and PIQ. Algorithms combined demographic variables with WAIS-III subtest raw scores. The algorithms accounted for 48–78% of the variance in FSIQ, 70–71% in VIQ, and 45–55% in PIQ. In the Validation group, the majority of the sample had predicted IQs that fell within a 95% CI band (FSIQ = 92–94%; VIQ = 93–95%; PIQ = 94–94%). These algorithms yielded reasonably accurate estimates of FSIQ, VIQ, and PIQ in this healthy adult population. It is anticipated that these algorithms will be useful as a means for estimating premorbid IQ scores in a clinical population. However, prior to clinical use, these algorithms must be validated for this purpose.

Keywords: Premorbid estimates; Intellectual functioning; Canadian WAIS-III norms

Canadian clinicians have long used American norms for the Wechsler intelligence batteries since the introduction of the Wechsler–Bellevue Intelligence Scale (Wechsler, 1939), and

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continuing with the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1955), the Wechsler Adult Intelligence Scale—revised (WAIS-R; Wechsler, 1981), and the Wechsler Adult Intelligence Scale—third edition (WAIS-III; Wechsler, 1997a). Until recently, only American norms were available for use with these tests. However, in one of the largest adaptations of the Wechsler scales to date, the Canadian Normative Supplement for the WAIS-III was published and distributed in 2001 (Wechsler, 2001). Normative data for 1105 Canadians between the ages of 16 and 84 are provided, stratified by 13 age groups. Normative data were generated using the continuous norming procedure proposed by Gorsuch and Kittrell (2001), rather than the traditional forced-normalization method used in the WAIS-R and the American WAIS-III.

The availability of the Canadian norms for the WAIS-III prompts clinicians in Canada to make a decision regarding which norms to use in clinical practice. Although it seems that the Canadian norms are the most appropriate and beneficial for use in Canada, there are several disadvantages to using these norms that make clinicians slow to embrace the new normative system. These disadvantages include the absence of demographically adjusted scores, the inability to compare WAIS-III scores with scores derived from the American-normed Wechsler Memory Scale—third edition (WMS-III; Wechsler, 1997b), and the uncertainty regarding how conclusions and inferences using these norms will be viewed in a medicolegal context. One dramatic limitation in drawing conclusions and inferences based on the Canadian norms is the inability to estimate premorbid intellectual functioning specific to this normative sample. In order to make assumptions about change in intellectual ability as a result of known or suspected brain dysfunction (i.e., deficit measurement), a comparison between current functioning and premorbid functioning must be made (e.g., Lezak, 1995).

There have been several methods developed to estimate premorbid intellectual functioning using the Wechsler intelligence batteries (see Schinka & Vanderploeg, 2000; Schoenberg, Scott, Duff, & Adams, 2002, for a more comprehensive review). These methods have included demographic based approaches (e.g., Barona, Reynolds, & Chastain, 1984; The Psychological Corporation, 2001), best current performance (e.g., Lezak, 1995), current reading ability (e.g., Blair & Spreen, 1989; The Psychological Corporation, 2001), historical achievement measures (e.g., Baade & Schoenberg, 2004; Schinka & Vanderploeg, 2000), and combined current ability and demographic variables (e.g., Krull, Scott, & Sherer, 1995; The Psychological Corporation, 2001; Schoenberg et al., 2002; Schoenberg, Duff, Dorfman, & Adams, 2004; Schoenberg, Duff, Scott, & Adams, 2003). Three of these methods have been utilized to estimate WAIS-III scores using the American norms. These include the use of (a) reading ability and (b) reading ability combined with demographic variables to estimate IQ and Index scores (The Psychological Corporation, 2001), and (c) the use of WAIS-III subtest performance and demographic variables to estimate scores for FSIQ, VIQ, PIQ (Schoenberg et al., 2002) and the General Ability Index (Lange, Schoenberg, Chelune, Scott, & Adams, 2005). However, because these methods were developed using the American WAIS-III standardization sample, these algorithms cannot be directly applied to the Canadian WAIS-III normative system.

A popular method for estimating premorbid intellectual ability on the Wechsler intelligence scales is by developing regression equations that estimate *current* IQ scores in a large healthy population (typically the standardization sample) that are then clinical validated as a means for estimating *premorbid* intellectual ability in patients with known neurological dysfunction. This method is based on the assumption that (a) estimates of premorbid intellectual/general cognitive functioning in healthy adults should result in estimated IQs that do *not* differ significantly from their current, actual, IQ score and (b) when applied to individuals with known or suspected neurological dysfunction, the algorithms should yield IQ estimates that are significantly greater than their actual IQs. Framed by these assumptions, estimates of premorbid functioning in individuals without neurological dysfunction should be equal to their actual ability level, thus not overestimating ability while simultaneously able to estimate premorbid ability level from combining behaviors thought to be resistant to neurological insult and demographic variables. This methodology has been used to develop premorbid estimates for the WAIS-R (i.e., Krull et al., 1995; Vanderploeg & Schinka, 1995), the American version of the WAIS-III (i.e., Schoenberg et al., 2002, 2003, in press, 2004; Lange et al., 2005), and both the revised and third edition Wechsler Intelligence Scale for Children (e.g., Reynolds & Gutkin, 1979; Vanderploeg, Schinka, Baum, Tremont, & Mittenberg, 1998).

To date, there are no available methods for estimating premorbid intellectual functioning using the Canadian WAIS-III normative system. The purpose of this study was to develop regression equations that combine demographic variables (i.e., age, education, gender, region of the country, and ethnicity) with WAIS-III subtest performance to estimate current Full Scale IQ, Verbal IQ, and Performance IQ scores in a large sample of healthy adults. The intended purpose of these algorithms is to provide a method that may prove useful for estimating *premorbid* IQ scores in patients with known or suspected neurological dysfunction.

1. Method

1.1. Participants

Participants consisted of those individuals with complete demographic data ($n = 1090$) from the Canadian WAIS-III standardization sample ($N = 1105$; Wechsler, 2001), obtained with permission from Harcourt Assessment, Inc. Demographic variables include age (in years), education (i.e., <8 years, Grade 9–11, High school diploma or equivalent, college/vocational/technical school, University degree), gender (male, female), region of the country (i.e., east, central, west), and ethnicity[1] (i.e., British, French/European, Multiple origin,

[1] An individual's ethnicity was determined based on the self-reported description of their ethnic background. Ethnicity is categorized into the following four categories. (a) *British*: includes those individual's who report their ethnic background to be from the British Isles. Countries include England, Scotland, Wales, and Ireland. Individual's who describe themselves as "Canadian" would be included in this category if their family background originated from the British Isles. Individual's whose family background includes the British Isles and another European country not from the British Isles should not be included in this category. These individuals would be included in the French/European category. (b) *French/European*: includes those individual's who report their ethnic background to be from France or other European countries not including the British Isles. Countries include, but are not limited to: France, Germany, Spain, Greece, Italy, Bulgaria, Denmark, Poland, Romania, Norway, Netherlands, Belgium, Ukraine, and Austria. Individuals who describe themselves as "Canadian" would be included in this category if their family background originated from one or more European countries not including the British Isles.

Other single origin). The Canadian WAIS-III standardization sample was selected to match the demographic characteristics of the 1991 Canadian Census (Statistics Canada, 1991) and is divided into 13 age groups ranging from age 16 to 84 years. Further details regarding the demographic characteristics and inclusion/exclusion criteria of this sample can be found in the WAIS-III Canadian technical manual (Wechsler, 2001).

1.2. Measures and procedure

The Canadian WAIS-III standardization sample was randomly divided into two groups. The first group was used to generate the IQ estimation algorithms (Development group, $n = 548$) and the second group was used to validate these algorithms (Validation group, $n = 542$). Differences between groups for age, IQ scores, and subtest raw scores were evaluated using one-way ANOVAs. Differences between groups for ethnicity, region of the country, gender, and education was evaluated using Chi-square analyses. Information regarding education was available only as categorical data and not as years of education. Performance measures consisted of the subtest raw scores of the Vocabulary (VO), Information (IN), Picture Completion (PC), and Matrix Reasoning (MR) subtests. These subtests were included because of their demonstrated reliability (The Psychological Corporation, 1997) and resistance to neurological insult (Donders, Tulsky, & Zhu, 2001; Fisher et al., 2000; Kaufman, 1990; Schoenberg et al., 2003; The Psychological Corporation, 1997).

Using a series of hierarchical regression analyses, prediction algorithms were generated for FSIQ, VIQ, and PIQ that used subtest raw scores and demographic variables as predictors. Eleven prediction algorithms were generated for FSIQ, and two prediction algorithms generated each for VIQ and PIQ. For FSIQ, one algorithm included all four subtests (i.e., IN/VO/MR/PC), six algorithms included all possible two-subtest combinations (i.e., IN/MR, VO/MR, IN/PC, VO/PC, VO/IN, PC/MR), and four algorithms included one individual subtest (i.e., IN, MR, VO, PC). For VIQ and PIQ scores, algorithms were generated using one individual subtests only (i.e., IN and VO for VIQ; MR and PC for PIQ). Algorithms using two-subtest combinations for VIQ and PIQ scores were not included due to expected redundancy across the dependent and independent variables. Prediction equations using demographic variables alone to estimate FSIQ, VIQ, and PIQ scores were also included for exploratory purposes. All demographic variables were dummy coded with the exception of age. The coding schema for demographic variables used in previous research (e.g., Barona et al., 1984; Krull et al.,

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Individual's whose family background includes French/European and another country not covered by the British or French/European category should not be included here. These individuals would be included in the Multiple Origin category. (c) *Single origin*: includes those individuals who report their ethnic background to be from a country not covered by the British or French/European category, and whose parents originate from the same country. For example, an individual with two parents that originated from South Africa. Countries and/or regions include, but are not limited to, Asia (e.g., Japan, China, Malaysia), Africa (South Africa, Nigeria, Kenya), Australia, New Zealand, Papua New Guinea, India, and South America (Brazil, Peru, Argentina). Individuals who describe themselves as "First Nations" should also be included in this category. (d) *Multiple origin*: includes those individuals who report their ethnic background to be from a country not covered by the British or French/European category, and whose parents are from two different countries. For example, an individual whose mother is East Indian and father is Malaysian. Countries included in this category include those specified in the single origin category.

1995; Lange et al., 2005; Schoenberg et al., 2002; Vanderploeg & Schinka, 1995) was not employed here because categorical variables (e.g., Ethnicity—1, African-American; 2, Hispanic; 3, Other; 4, Caucasian) that are included as independent measures in regression analyses should not, from a purely statistical standpoint, be treated as continuous variables.[2]

For each subtest model, five hierarchical regression analyses were completed using the target IQ score as the dependent variable, and demographic variables and subtest raw scores as the independent measures. For each of the five hierarchical regression analyses, all relevant subtest scores were forced into the regression analyses on the first step, followed by each of the five demographic variables (i.e., age, education, region of the country, gender, and ethnicity) in five subsequent steps. Age in years was entered as a continuous variable. Education, region of the country, gender, and ethnicity were each entered into the regression as a set of dummy coded variables. The significance of each demographic variable was tested over and above all other variables on the final step of the hierarchy using R^2 change statistics. Any demographic variable that did not add significantly ($P < .05$) to the estimation of IQ scores in the final step was excluded from the equation. When one or more demographic variables were excluded during this first stage of equation building, the process was repeated using the remaining demographic variables until all remaining demographic variables contributed significantly to the regression equation.

2. Results

Descriptive statistics, chi-square analyses, and ANOVA results for the demographic variables and WAIS-III measures by group are presented in Tables 1 and 2. There were no significant differences between the Development and Validation groups on any of the demographic variables (i.e., age, education, gender, ethnicity, region of the country), IQs, or subtest raw scores.

Using the Development group ($n = 548$), 18 regression algorithms were generated: (a) 11 algorithms estimating FSIQ, (b) 2 algorithms estimating VIQ, (c) 2 algorithms estimating PIQ using WAIS-III subtest performance and demographic variables, and (d) 1 algorithm each to estimate FSIQ, VIQ, and PIQ using demographic variables alone. Summary results for the regression equations are presented in Table 3 and the equations can be found in the Appendix. All algorithms were significant predictors of FSIQ, VIQ, and PIQ (all $P < .001$). Algorithms that combined demographic variables with subtest performance accounted for 48.4–78.1% of the variance in FSIQ, 69.9–71.3% of the variance in VIQ, and 45.1–54.9% of the variance in PIQ depending on the subtests employed. Algorithms that included demographic variables alone (i.e., FSIQ-DEM, VIQ-DEM, and PIQ-DEM) accounted for 31.1% of the variance in FSIQ, 35.5% of the variance in VIQ, and 13.5% of the variance in PIQ.

[2] It should be noted that a comparison between statistical methods was completed with the WAIS-III US standardization sample. There was no significant difference in average estimated GAI scores for the sample using algorithms derived from statistical analyses in which demographic variables were treated as continuous variables versus algorithms in which demographic variables were dummy coded (Lange et al., 2005). The algorithms using dummy coding for demographic variables are presented here to be most consistent with statistical principals.

Table 1
Descriptive statistics of demographic variables by group: Chi-square analysis

	Development group		Validation group		X^2	*p*
	N	%	*N*	%		
Education						
≤8 years	48	8.8	41	7.6	.740	.946
9–11 years	99	18.1	104	19.2		
High school	89	16.2	86	15.9		
College	191	34.9	193	35.6		
University	121	22.1	118	21.8		
Gender						
Male	312	56.9	310	57.2	.008	.931
Female	236	43.1	232	42.8		
Ethnicity						
British	206	37.6	203	37.5	5.506	.138
French/European	184	33.6	152	28.0		
Multiple origin	111	20.3	133	24.5		
Single origin	47	8.6	54	10.0		
Region						
West	230	42.0	217	40.0	.795	.672
Central	267	48.7	267	49.3		
East	51	9.3	58	10.7		

Note: $N = 1090$. Development group ($n = 548$), Validation group ($n = 542$). *Data*: all data are derived from the Canadian standardization sample of the *Wechsler Adult Intelligence Scale—third edition*.

Table 2
Means and standard deviations of WAIS-III scores by age group: analysis of variance

	Development group		Validation group		*F*	*p*
	M	S.D.	*M*	S.D.		
Full Scale IQ	103.2	14.5	102.4	15.4	.74	.39
Verbal IQ	103.5	14.8	102.5	15.2	1.12	.29
Performance IQ	102.1	14.0	101.5	14.3	.46	.50
Information (raw)	17.6	5.4	17.4	5.6	.54	.46
Vocabulary (raw)	45.3	12.3	44.6	12.8	.87	.35
Matrix Reasoning (raw)	15.9	5.9	16.3	5.7	1.23	.27
Picture Completion (raw)	19.8	3.8	19.6	3.8	.66	.42
Age (in years)	43.0	21.4	41.2	20.5	1.86	.17

Note: $N = 1090$. Development group ($n = 548$), Validation group ($n = 542$). *Data*: all data are derived from the Canadian standardization sample of the *Wechsler Adult Intelligence Scale—third edition*.

Table 3
Regression results summary for estimating IQ scores from demographic variables and WAIS-III subtest raw scores: Development group

Subtest model	R^2	SEE	*F*	*p*	Demographic variables excluded
Full Scale IQ					
FSIQ (4ST)	.78	60.88	158.54	<.001	Region, gender
FSIQ (VO/MR)	.73	7.65	159.01	<.001	Ethnicity, gender
FSIQ (IN/MR)	.73	7.69	128.64	<.001	Region
FSIQ (IN/PC)	.67	8.39	100.10	<.001	Region
FSIQ (VO/PC)	.67	8.46	107.34	<.001	Ethnicity
FSIQ (VO/IN)	.66	8.58	146.40	<.001	Region, gender, ethnicity
FSIQ (MR/PC)	.63	8.88	77.10	<.001	Gender
FSIQ (VO)	.59	9.32	112.51	<.001	Region, ethnicity
FSIQ (IN)	.60	9.24	81.40	<.001	Region
FSIQ (MR)	.58	9.55	66.18	<.001	Gender
FSIQ (PC)	.48	10.53	45.79	<.001	Gender
FSIQ (DEM)	.31	12.17	21.99	<.001	Nil
Verbal IQ					
VIQ (VO)	.71	7.98	148.35	<.001	Ethnicity
VIQ (IN)	.70	8.18	124.56	<.001	Region
VIQ (DEM)	.36	11.98	26.77	<.001	Nil
Performance IQ					
PIQ (MR)	.55	9.47	72.79	<.001	Region, gender
PIQ (PC)	.45	10.44	55.41	<.001	Ethnicity, gender
PIQ (DEM)	.14	13.10	12.02	<.001	Ethnicity, gender

Note: $n = 548$; FSIQ, Full Scale IQ; VIQ, Verbal IQ; PIQ, Performance IQ; PC, Picture Completion; MR, Matrix Reasoning; VO, Vocabulary; IN, Information; 4ST, estimated FSIQ using all four subtests; DEM, Demographic variables only; SEE, Standard Error of Estimate. *Data*: All data are derived from the Canadian standardization sample of the *Wechsler Adult Intelligence Scale—third edition*.

Of the 18 algorithms evaluated, only two algorithms retained all five demographic variables as significant predictors of index scores (i.e., FSIQ and VIQ algorithms using demographic variables only). One of the five demographic variables was excluded from eight algorithms and two demographic variables excluded from six algorithms. Across all 18 algorithms, the demographic variable excluded most frequently was gender (nine algorithms), followed by region of the country (eight algorithms), and ethnicity (seven algorithms). Education and age were not excluded from any of the 18 algorithms.

To evaluate the accuracy of estimated IQ scores, the FSIQ, VIQ, and PIQ algorithms were used to generate estimated IQ scores for each individual of the Validation group. Descriptive statistics, paired-samples *t*-tests, and Pearson correlations between actual and estimated IQ scores are presented in Table 4. The average estimated FSIQ, VIQ, and PIQ did not differ significantly from the average actual corresponding IQ of the Validation group. The correlations between estimated and actual IQs were significant for all FSIQ, VIQ, and PIQ algorithms ($P < .001$), and ranged from $r = .51$ to .88 for FSIQ, $r = .54$ to .85 for VIQ, and $r = .37$ to .72 for PIQ. The correlation between estimated and obtained IQ scores using algorithms that

Table 4
Descriptive statistics, mean comparisons, and correlation results between actual and estimated WAIS-III IQ Scores: Validation group

	Obtained scores		Obtained vs. estimated IQ		Actual range		Theoretical range[a]	
	M	S.D.	*p*	*r*	Min	Max	Min	Max
Obtained IQ								
FSIQ	102.4	15.4	–	–	67	153	46	155
VIQ	102.5	15.2	–	–	66	151	49	155
PIQ	101.5	14.3	–	–	61	155	45	155
Predicted FSIQ								
FSIQ (4ST)	102.7	13.4	.471	.88	65.1	134.1	37.1	144.1
FSIQ (VO/MR)	102.9	12.9	.236	.85	67.5	131.2	45.6	142.4
FSIQ (IN/MR)	103.0	12.8	.138	.84	67.6	133.1	47.9	143.3
FSIQ (IN/PC)	102.4	12.5	.980	.81	70.4	129.4	42.4	136.5
FSIQ (VO/PC)	102.2	12.3	.574	.82	67.3	127.4	39.4	135.1
FSIQ (VO/IN)	102.5	12.3	.860	.82	70.8	125.7	59.2	128.9
FSIQ (MR/PC)	102.9	11.5	.251	.79	72.3	132.6	36.4	147.3
FSIQ (VO)	102.5	11.6	.825	.79	69.9	124.4	61.2	128.2
FSIQ (IN)	102.7	11.8	.541	.76	74.3	125.6	60.9	130.4
FSIQ (MR)	103.3	10.9	.056	.75	73.6	131.2	51.9	144.2
FSIQ (PC)	102.4	10.0	.992	.68	65.4	126.3	43.4	135.2
FSIQ (DEM)	102.9	8.1	.385	.51	82.2	124.6	75.6	126.6
Predicted VIQ								
VIQ (VO)	102.7	13.0	.689	.82	67.3	127.7	53.9	132.5
VIQ (IN)	103.0	12.9	.252	.85	71.6	128.7	59.0	133.5
VIQ (DEM)	103.2	8.7	.210	.54	80.8	127.1	74.2	129.0
Predicted PIQ								
PIQ (MR)	102.2	10.2	.084	.72	73.1	130.4	55.9	138.4
PIQ (PC)	101.2	9.2	.584	.66	56.4	120.9	44.2	129.0
PIQ (DEM)	101.9	5.1	.518	.37	87.9	114.6	87.8	115.4

Note: $n = 542$; FSIQ, Full Scale IQ; VIQ, Verbal IQ; PIQ, Performance IQ; PC, Picture Completion subtest raw score; MR, Matrix Reasoning subtest raw score; VO, Vocabulary subtest raw score; IN, Information subtest raw score; 4ST, estimated FSIQ using 4 subtests (i.e., IN, VO, MR, PC); DEM, Demographic variables only. *Data*: all data are derived from the Canadian standardization sample of the *Wechsler Adult Intelligence Scale—third edition*.

[a] Theoretical range is absolute minimum and maximum that may be obtained from each algorithm.

combined only demographic variables was $r = .51$ for FSIQ, $r = .54$ for VIQ, and $r = .37$ for PIQ. When demographic variables are combined with subtest performance, the correlation between estimated and obtained IQ scores ranged from $r = .68$ to .88 for FSIQ, $r = .82$ to .85 for VIQ, and $r = .66$ to .72 for PIQ depending on the subtests employed (Table 4).

To examine the accuracy of the FSIQ, VIQ, and PIQ algorithms at an individual level, each participant's estimated IQ was compared to their actual IQ to determine the base rate of estimation errors using six criteria. Table 5 presents estimation errors as a percentage of cases

Table 5
Predictive accuracy of estimated IQ scores: Validation group

Prediction algorithm	Percent within					
	±5 Points	±10 Points	Same category[a]	One category	One SEE	95% CI Band
Full Scale IQ						
FSIQ (4ST)	57.7	87.1	62.2	97.2	67.9	92.8
FSIQ (VO/MR)	51.8	82.5	57.4	96.3	65.9	93.5
FSIQ (IN/MR)	50.2	80.3	56.8	95.6	66.1	92.3
FSIQ (IN/PC)	47.6	76.4	57.6	94.3	68.3	92.6
FSIQ (VO/PC)	48.7	78.4	56.8	94.3	69.2	93.9
FSIQ (VO/IN)	49.8	79.7	55.5	95.0	68.8	94.1
FSIQ (MR/PC)	44.3	75.8	55.7	92.6	68.3	93.9
FSIQ (VO)	46.7	75.6	51.3	91.5	70.1	94.3
FSIQ (IN)	43.9	72.1	50.9	93.0	66.1	91.9
FSIQ (MR)	41.0	73.6	49.6	91.7	67.5	93.7
FSIQ (PC)	39.1	66.4	50.7	89.5	66.4	93.5
FSIQ (DEM)	32.7	60.5	46.9	84.1	67.3	92.8
Verbal IQ						
VIQ (VO)	52.0	83.2	54.2	95.0	70.5	94.5
VIQ (IN)	47.4	78.4	53.5	94.1	66.4	93.2
VIQ (DEM)	35.1	61.1	44.5	84.3	66.1	93.7
Performance IQ						
PIQ (MR)	43.9	72.0	56.6	92.6	67.5	93.5
PIQ (PC)	42.6	69.6	57.9	90.4	68.8	93.4
PIQ (DEM)	37.3	61.6	57.2	84.1	72.0	93.7

Note: $n = 542$; SEE, Standard Error of Estimate; CI, Confidence Interval; FSIQ, Full Scale IQ; VIQ, Verbal IQ; PIQ, Performance IQ; PC, Picture Completion; MR, Matrix Reasoning; VO, Vocabulary; IN, Information; 4ST, all four subtests; DEM, Demographic variables only. *Data*: All data are derived from the Canadian standardization sample of the *Wechsler Adult Intelligence Scale—third edition*. Copyright © 1997 by The Psychological Corporation, a Harcourt Assessment Company. Used by permission. All rights reserved.

[a] Category = ability classification (e.g., Borderline, Low Average, Superior, etc.).

whose estimated IQ score fell within (a) ±5 points of their actual IQ, (b) ±10 points of their actual IQ, (c) the same ability classification level (ranging from *extremely low* to *very superior*), (d) one ability classification range, (e) +1 SEE, and (f) the 95% confidence interval. McNemar's test of paired proportions was used to compare the predictive accuracy of each algorithm. Using ±10 points as the criterion, the predictive accuracy of estimated FSIQ using the FSIQ-4ST algorithm was significantly higher compared to all other FSIQ algorithms (range: $P < .001$ to $P = .003$). The second highest rate of prediction accuracy was yielded by the FSIQ-VO/MR algorithm. The predictive accuracy of this algorithm was significantly higher than the majority of the other algorithms (range: $P < .001$ to $P = .022$), with the exception of FSIQ-VO/PC ($P = .411$) and FSIQ-IN/VO ($P = .836$). The lowest predictive accuracy rate was yielded by the FSIQ-DEM algorithm which was significantly lower than all other FSIQ algorithms (range: $P < .001$ to $P = .003$). For VIQ and PIQ, the least accurate estimates were again obtained when using demographic variables alone (all $P < .001$). The most accurate estimates for VIQ were obtained using the VIQ-VO algorithm ($P < .001$ to $P = .029$), followed by the VIQ-IN algorithm (i.e., VIQ-VO > VIQ-IN > VIQ-DEM). The most accurate estimates of PIQ were obtained when using either the PIQ-MR or PIQ-PC algorithm (i.e., PIQ-MR & PIQ-PC > PIQ-DEM).

The influence of demographic variables and ability level on the predictive accuracy (i.e., difference score between estimated and actual score) of the algorithms was explored using bivariate correlations. Correlations between prediction errors and gender, region of the country, and education were not significant and consistently low (gender, $r < .08$; region, $r < .06$; education, $r < .08$) for all algorithms. Although significant, the correlations between gender and FSIQ-VO/MR ($r = .10$), region and FSIQ-VO/PC ($r = .09$), region and PIQ-PC ($r = .09$), education and PIQ-PC ($r = .09$), education and PIQ-MR ($r = .09$) were not meaningful. The correlation between prediction errors and IQ score level was moderate to high for all FSIQ, VIQ, and PIQ algorithms, ranging from $r = .49$ to .76 for FSIQ, $r = .52$ to .82 for VIQ, and $r = .70$ to .94 for PIQ. A significant but weak relationship between prediction errors and age was also observed that ranged from $r = .13$ to .17 for FSIQ, $r = .12$ to .14 for VIQ, and $r = .03$ to .10 for PIQ. A significant association between prediction errors and ethnicity was observed for some of the FSIQ and VIQ algorithms, however, the strength of this association was weak (FSIQ, $r < .12$; VIQ, $r < .11$).

Prediction errors as a function of IQ ability level (e.g., extremely low to very superior ranges) are presented in Table 6. The percent of estimation errors are presented for FSIQ-4ST, FSIQ-VO/MR, VIQ-VO, and PIQ-MR. Chi-square analyses revealed that the predictive accuracy of all four algorithms was consistently and significantly lower for individuals with obtained FSIQ, VIQ and PIQ scores falling in the Very Superior range ($P < .001$). For FSIQ-4ST, FSIQ-VO/MR, and VIQ-VO algorithms, there were no differences in predictive accuracy rates for individuals in the Borderline to Superior ability classifications ranges. However, for the PIQ-MR algorithm, predictive accuracy rates varied across ability classification levels. Higher predictive accuracy rates were yielded by individuals with PIQ scores in the Average and High Average ranges, followed by those with PIQ scores in the low average range, then those in the Borderline and Superior ranges.

3. Discussion

This study developed algorithms to estimate FSIQ, VIQ, and PIQ scores using the Canadian WAIS-III standardization sample that combined subtest raw scores with demographic variables. Overall, the algorithms provided reasonably accurate estimates of IQs in this healthy adult population. Accuracy rates were highest when estimating FSIQ from demographic variables and four subtests (FSIQ-4ST). Though significantly lower than the FSIQ-4ST algorithm, high rates of prediction accuracy were also found when using the FSIQ-VO/MR algorithm. Accurate prediction of VIQ and PIQ scores were highest when demographic variables were combined with the Vocabulary subtest for VIQ scores (i.e., VIQ-VO), and the Matrix Reasoning subtest (PIQ-MR) or Picture Completion subtest (PIQ-PC) for PIQ scores. The observed range of estimated IQ scores using these algorithms (i.e., 65–134 for FSIQ-4ST, 67–128 for VIQ-VO, 56–121 for PIQ-PC, and 73–130 for PIQ-MR) closely approximated the range of actual IQ scores in the Canadian WAIS-III standardization sample (FSIQ range = 67–153; VIQ

Table 6
Predictive accuracy of estimated IQ scores by ability level: Validation group

Prediction algorithm	Percent within					
	±5 Points	±10 Points	Same category[a]	One category	One SEE	95% CI Band
FSIQ (4ST)						
≤Borderline	66.7	97.4	59.0	100	76.9	100
Low average	67.7	89.2	49.2	100	75.4	90.8
Average	59.1	89.2	76.2	99.6	70.3	94.8
High average	65.6	93.8	57.3	100	77.1	97.9
Superior	43.5	84.8	41.3	93.5	50.0	89.1
Very superior	3.7	25.9	11.1	59.3	11.1	55.6
FSIQ (VO/MR)						
≤Borderline	48.7	82.1	43.6	97.4	61.5	100
Low average	47.7	78.5	33.8	100	60.0	92.3
Average	54.6	87.7	71.4	99.3	70.3	95.2
High average	68.8	89.6	62.5	100	80.2	95.8
Superior	37.0	73.9	37.0	87.0	60.9	95.7
Very superior	3.7	33.3	11.1	59.3	3.7	63.0
VIQ (VO)						
≤Borderline	37.8	78.4	32.4	83.8	56.8	94.6
Low average	60.3	83.3	44.9	98.7	64.1	89.7
Average	55.5	87.4	68.8	98.0	67.2	93.1
High average	56.6	90.9	55.6	100	77.8	98.0
Superior	48.3	81.7	36.7	90.0	56.7	90.0
Very superior	0	9.5	0	57.1	0	38.1
PIQ (MR)						
≤Borderline	15.4	35.9	7.7	64.1	20.5	74.4
Low average	31.9	66.0	25.5	95.7	42.6	80.9
Average	53.0	81.5	76.7	99.4	70.0	94.9
High average	47.8	82.6	53.3	98.9	62.0	93.5
Superior	22.6	41.9	6.5	74.2	25.8	80.6
Very superior	0	10.0	5.0	35.0	10.0	25.0

Note: $n = 542$; SEE, Standard Error of Estimate; CI, Confidence Interval; FSIQ, Full Scale IQ; VIQ, Verbal IQ; PIQ, Performance IQ; PC, Picture Completion; MR, Matrix Reasoning; VO, Vocabulary; IN, Information; 4ST, all four subtests. Borderline and Extremely Low categories were combined due to low numbers in the Extremely Low category. *Data*: All data are derived from the Canadian standardization sample of the *Wechsler Adult Intelligence Scale—third edition*.

[a] Category = ability classification (e.g., Borderline, Low Average, Superior, etc.).

range = 66–151; PIQ range = 61–155). However, prediction accuracy was consistently lower for individuals with IQs in the Very Superior range.

These results are similar with previous algorithms that combine current performance with demographic data to estimate intellectual functioning on the WAIS-R and American WAIS-III (e.g., Krull et al., 1995; Schoenberg et al., 2002, 2004; Vanderploeg & Schinka, 1995). Despite the prediction errors for individuals at the upper end of the score distribution, comparison of these algorithms to other premorbid estimation methods for FSIQ, VIQ, and PIQ developed using the American WAIS-III normative system suggest the current algorithms hold promise. The proportion of FSIQ, VIQ, and PIQ estimates that were within 10 points of actual IQ scores in this study (i.e., FSIQ = 66.4–87.1%; VIQ = 78.4–83.2%; PIQ = 72.0–69.6%) was similar to that yielded by the OPIE-3 (i.e., FSIQ = 75.4–93.2%; VIQ = 85.6%, PIQ = 73.7%), WTAR (i.e., FSIQ = 70.4%, VIQ = 70.8%, PIQ = 61.3%; The Psychological Corporation, 2001), and the combined WTAR-demographics approach (FSIQ = 73.4%, VIQ = 76.1%, PIQ = 63.6%; The Psychological Corporation, 2001).

A number of issues that potentially limits the clinical usefulness of these algorithms should be noted. These issues have been detailed elsewhere (e.g., Schoenberg et al., 2002; Lange et al., 2005) and are briefly reviewed here. First, the inclusion of WAIS-III subtests when estimating IQ scores may lead to redundancy between the independent and dependent variables. Second, the number of years of education was not used in the current model and was instead based on five educational categories. The effect of varying degrees of education cannot be evaluated because education level was limited to these broad categories. This is especially problematic for individuals classified as having 9–11 years education, college/vocational/technical school, and University degrees. In these categories, specific distinctions cannot be made between educational level. Third, occupation data was not available. The failure to take into account occupation status may adversely affect estimating IQs for high functioning individuals whom leave school early. Estimates of IQ may be obtained for individuals aged 16–84, however, the education coding for 16–19-year-olds were based on their parents level of education, and IQ estimations for 16–19-year-olds should be made with caution.

The application of these algorithms as a procedure to estimate premorbid IQ has not been demonstrated and is therefore not yet recommended for clinical use. The development of the algorithms is only the first step. FSIQ, VIQ, and PIQ derived estimates within well defined patient samples with known brain injury are needed to assess the clinical utility of these IQ algorithms as a procedure to predict *premorbid* intellectual functioning. In addition, clinical research is required to determine which of these algorithms is most effective in a clinical population. Based on past research predicting premorbid IQ on the WAIS-R and WAIS-III (e.g., Axelrod, Vanderploeg, Schinka, 1999; Scott, Krull, Williamson, Adams, & Iverson, 1997; Schoenberg et al., 2002, 2003), it is anticipated that these algorithms will demonstrate clinical utility as an estimate of premorbid IQ. Clinical validation of the WAIS-III Estimate of Premorbid Ability for Canadians (EPAC) may include an evaluation of score discrepancies between actual and estimated IQ scores with patient samples having known brain injury. Additional validation could be obtained from clinical samples in which independent premorbid indexes of cognitive functioning (e.g., standardized achievement tests) and WAIS-III FSIQ scores are available (Baade & Schoenberg, 2004).

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Appendix A

Algorithms for estimating FSIQ, VIQ, and PIQ scores using the Canadian WAIS-III normative data.

FSIQ (4ST) = 37.81 + (IN × .76) + (VO × .35) + (MR × .92) + (PC × .67) + (Age × .21) + Education + Ethnicity

Education[a]	<8 years (nil)	9–11 years (−1.51)	HS (−1.41)	College (.17)	Uni (1.57)
Ethnicity	British (nil)	French (.94)	Multiple (.37)	Single (−2.55)	

FSIQ (VO/MR) = 44.74 + (VO × .62) + (MR × 1.22) + (Age × .22) + Education + Region

Education	<8 years (nil)	9–11 years (−1.08)	HS (.20)	College (1.11)	Uni (3.55)
Region	West (nil)	Central (1.87)	East (−1.61)		

FSIQ (IN/MR) = 50.86 + (IN × 1.37) + (MR × 1.16) + (Age × .21) + Education + Ethnicity + Gender

Education	<8 years (nil)	9–11 years (.30)	HS (2.06)	College (3.43)	Uni (5.25)
Ethnicity	British (nil)	French (−1.76)	Multiple (−.24)	Single (−4.48)	
Gender	Female (nil)	Male (−1.84)			

FSIQ (IN/PC) = 46.00 + (IN × 1.52) + (PC × 1.18) + (Age × .13) + Education + Ethnicity + Gender

Education	<8 years (nil)	9–11 years (.36)	HS (1.01)	College (4.22)	Uni (6.86)
Ethnicity	British (nil)	French (−1.45)	Multiple (−.41)	Single (−3.87)	
Gender	Female (nil)	Male (−1.82)			

FSIQ (VO/PC) = 41.50 + (VO × .67) + (PC × 1.19) + (Age × .14) + Education + Region + Gender

Education	<8 years (nil)	9–11 years (−1.44)	HS (−1.13)	College (1.97)	Uni (5.18)
Region	West (nil)	Central (.35)	East (−2.94)		
Gender	Female (nil)	Male (1.60)			

FSIQ (IN/VO) = 59.56 + (IN × 1.08) + (VO × .48) + (Age × .05) + Education

Education	<8 years (nil)	9–11 years (−1.16)	HS (−.82)	College (1.53)	Uni (2.96)

FSIQ (MR/PC) = 39.41 + (MR × 1.31) + (PC × 1.11)+ (Age × .35) + Education + Ethnicity + Region

Education	<8 years (nil)	9–11 years (2.66)	HS (6.20)	College (8.93)	Uni (14.54)
Ethnicity	British (nil)	French (−2.24)	Multiple (−1.05)	Single (−4.70)	
Region	West (nil)	Central (.37)	East (−3.92)		

FSIQ (VO) = 61.22 + (VO × .80) + (Age × .07) + Education + Gender

Education	<8 years (nil)	9–11 years (−1.12)	HS (−.43)	College (2.50)	Uni (5.43)
Gender	Female (nil)	Male (2.51)			

FSIQ (IN) = 66.60 + (IN × 1.80) + (Age × .06) + Education + Ethnicity + Gender

Education	<8 years (nil)	9–11 years (.93)	HS (2.57)	College (5.49)	Uni (8.02)
Ethnicity	British (nil)	French (−1.75)	Multiple (−.52)	Single (−4.91)	
Gender	Female (nil)	Male (−1.74)			

Appendix A (*Continued*)

FSIQ (MR) = 55.72 + (MR × 1.63) + (Age × .33) + Education + Ethnicity + Region					
Education	<8 years (nil)	9–11 years (3.43)	HS (8.26)	College (10.48)	Uni (16.29)
Ethnicity	British (nil)	French (−2.55)	Multiple (−1.13)	Single (−5.61)	
Region	West (nil)	Central (.44)	East (−3.52)		
FSIQ (PC) = 50.19 + (PC × 1.80) + (Age × .23) + Education + Ethnicity + Region					
Education	<8 years (nil)	9–11 years (3.81)	HS (7.18)	College (12.35)	Uni (19.54)
Ethnicity	British (nil)	French (−2.47)	Multiple (−1.61)	Single (−4.58)	
Region	West (nil)	Central (−1.74)	East (−5.86)		
VIQ (VO) = 56.19 + (VO × .91) + (Age × .07) + Education + Region + Gender					
Education	<8 years (nil)	9–11 years (−.91)	HS (−.55)	College (1.45)	Uni (5.98)
Region	West (nil)	Central (1.48)	East (−2.54)		
Gender	Female (nil)	Male (2.57)			
VIQ (IN) = 64.26 + (IN × 1.98) + (Age × .06) + Education + Ethnicity + Gender					
Education	<8 years (nil)	9–11 years (.98)	HS (2.34)	College (4.67)	Uni (8.41)
Ethnicity	British (nil)	French (−2.98)	Multiple (−.80)	Single (−4.28)	
Gender	Female (nil)	Male (−1.96)			
PIQ (MR) = 54.54 + (MR × 1.92) + (Age × .32) + Education + Ethnicity					
Education	<8 years (nil)	9–11 years (1.02)	HS (3.75)	College (4.53)	Uni (5.01)
Ethnicity	British (nil)	French (.20)	Multiple (.49)	Single (−3.79)	
PIQ (PC) = 44.02 + (PC × 2.29) + (Age × .22) + Education + Region					
Education	<8 years (nil)	9–11 years (1.10)	HS (2.11)	College (6.26)	Uni (8.16)
Region	West (nil)	Central (−1.96)	East (−3.30)		

Note: These algorithms should not be used as a method for estimating premorbid intellectual ability in patients with known or suspected neurological dysfunction until formal clinical validation studies have been completed. FSIQ = Full Scale IQ; VIQ = Verbal IQ; PIQ = Performance IQ; PC = Picture Completion; MR = Matrix Reasoning; VO = Vocabulary; IN = Information; 4ST = all four subtests. Age = Age in years. *Education*: HS = High school diploma or equivalent; Uni = University degree; College = College, vocational, or technical school. *Ethnicity*: French = French/European; Single = Single origin; Multiple = Multiple origin; *Region*: East = Maritime provinces together with English speaking sites in Quebec; Central = Ontario; West = Manitoba, Saskatchewan, Alberta, British Columbia, and Canada's northern regions (i.e., Northwest Territories, Yukon, Nunavut); nil = beta weight that is zero or nearly zero and contributes less than .5 points to the estimated IQ. *Data*: all data are derived from the Canadian standardization sample of the *Wechsler Adult Intelligence Scale—third edition*.

[a] Insert values for the relevant demographic variables into the equation.

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