Physical Functioning Is Associated With Processing Speed and Executive Functions in Community-Dwelling Older Adults

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Objectives. The aim of this study was to examine the association between physical functioning and cardiovascular burden on the cognitive performance of community-dwelling older adults.

Method. Ninety-three adults aged 60 and older completed a medical evaluation by a geriatrician, performance-based physical tests, and neuropsychological assessments. Cognitive composite scores (memory, speed, and executive) as well as a physical functioning score were created by averaging standardized z-scores of selected tests. A cardiovascular burden index was also computed by totalling the number of cardiovascular risk factors and diseases.

Results. Multiple hierarchical regression analyses reveal that higher level of physical functioning was significantly associated with greater processing speed and better executive functions but was not associated with memory performance. These relations were independent of age, sex, and level of education. Cardiovascular burden was not significantly associated with any cognitive domain.

Discussion. These results suggest that cognition is related to simple performance-based physical tests and highlight the importance of intervention studies aimed at enhancing cognitive and physical functioning in older adults.

Key Words: Cardiovascular risk factors—Cognition—Executive functions—Physical functioning—Processing speed.

Age-related cognitive decline is associated with loss of independence, institutionalization, and poor quality of life (Luppa et al., 2010; St John, Montgomery, Kristjansson, & McDowell, 2002). Nevertheless, cognitive decline is not an inevitable outcome of aging. Indeed, a large proportion of older adults maintain a high level of cognitive functioning throughout life. Differences in functional and medical status appear to partly explain these variations in cognitive functioning, but the extent of their contribution remains understudied. Identifying factors that are associated with cognitive functioning could help clarify how cognitive abilities and well-being are maintained in old age and lead to the development of targeted interventions to enhance cognitive performance.

Several studies have reported a relationship between physical functioning and cognition in older adults. For instance, changes in gait rhythm and pace have been, respectively, associated with decline in episodic memory and executive functions in a nonrandomized sample of adults aged 70 and older (Verghe, Wang, Lipton, Holtzer, & Xue, 2007). Change in the variability factor of gait was in turn associated with a greater risk of dementia over the 5-year follow-up period. Furthermore, a 20-year longitudinal study of healthy older adults showed a steeper gait speed decline 12 years prior to the occurrence of mild cognitive impairment (Buracchio, Dodge, Howieson, Wasserman, & Kaye, 2010). In addition to gait speed, other physical function parameters have been linked to cognition. Muscle strength, frequently estimated using handgrip strength, also predicts cognitive performance and dementia risk in older adults (Alfaro-Acha et al., 2006; Boyle, Buchman, Wilson, Leurgans, & Bennett, 2009; Taekema, Gusseklooo, Maier, Westendorp, & de Craen, 2010). Motor slowing and muscle strength thus appear to be valid markers of cognitive deterioration. Noticeably, most of these studies used broad measures of general cognitive functioning, such as MMSE. This does not allow distinguishing between multiple cognitive functions that may differentially be related to physical functioning and not equally affected by age. Moreover, they typically focused on only one parameter of physical functioning. Rosano and colleagues (2005) used three different tests of physical functioning (gait speed, chair stands, and
standing balance) to test their relationship with two cognitive tests that target processing speed and a measure of global cognition. They showed that all tests of physical performance significantly predicted both cognitive tests. Further, they found a stronger relationship between physical performance and speed of processing than between physical performance and a global cognition measure. In this study, we aimed at extending the range of physical functions and cognitive domains assessed in order to further understand how physical functioning affects specific cognitive functions.

A common explanatory factor likely underlies the co-occurrence of cognitive and physical decline in aging (Christensen, Mackinnon, Korten, & Jorm, 2001). Both cognitive and physical functioning rely mainly on central biological processes that are sensitive to aging. Physical function impairment may reflect a generalized reduction in the efficiency of the central nervous system that simultaneously affects cognitive performance. However, the rate of decline of different cognitive functions during aging is heterogeneous. Although crystallized abilities, such as general knowledge and verbal abilities, remain intact or even improve with age, fluid aspects of intellectual functioning appear to be more sensitive to the aging process (Baltes, Staudinger, & Lindenberger, 1999; Park & Gutcheon, 2002). Slowing of processing speed is generally acknowledged as a hallmark of cognitive aging (Salthouse, 1996), but a large body of evidence also proposes that executive functions are particularly sensitive to normal aging (Bherer, Belleville, & Hudon, 2004). Executive functions are higher level cognitive functions used to perform complex goal-directed tasks that require inhibiting an automatic behavior, alternating between several tasks or updating information in working memory. Previous research has highlighted the important contribution of impaired executive functions in the etiology of functional disability. For example, Cahn-Weiner and coworkers (2000) showed that executive functioning predicted performance in instrumental activities of daily living (IADL), whereas memory, language, visuospatial abilities, and psychomotor speed did not significantly predict functional status. Similar results were reported in Grigsby and colleagues’ study (1998), where executive functions predicted both self-reported and directly observed ADL and IADL performance (see also Carlson et al., 1999; Johnson, Lui, & Yaffe, 2007). These observations suggest that predicting executive functions may help identify older adults more at risk of IADL decline.

The integrity of brain structure and functions is partly influenced by vascular factors. Because 9 older adults out of 10 have at least one cardiovascular risk (CVR) factor in Canada (Public Health Agency of Canada, 2009), this issue is fundamental for the prediction of cognitive functioning in this population. However, few studies have addressed the contribution of vascular burden in the relationship between physical functioning and cognition. A large body of research has shown that CVR factors are associated with cognitive decline and a higher risk of vascular dementia, but also Alzheimer’s disease (Whitmer, Sidney, Selby, Johnston, & Yaffe, 2005). Hypertension (Papademetriou, 2005; Tzourio, Dufouil, Ducimetiere, & Alperovitch, 1999), diabetes mellitus (Kuo et al., 2005; McCrimmon, Ryan, & Frier, 2012), coronary heart diseases (Singh-Manoux et al., 2008), and obesity (Whitmer, Gunderson, Barrett-Connor, Quesenberry, & Yaffe, 2005), among others, have been recognized as leading risk factors for dementia and cognitive impairment without dementia, independently of the risk of stroke or major cardiac event (see Duron & Hanon, 2008, for a review). Some studies have shown that the accumulation of factors has a better predictive value of cognitive performance than each factor taken alone (Carmelli et al., 1998; Song, Mitnitski, & Rockwood, 2005; Villeneuve, Belleville, Massoud, Bocti, & Gauthier, 2009). Therefore, in this study, a cumulative approach was chosen to represent the amount of cardiovascular burden in our participants.

CVR factors have been associated with executive impairment (Hajjar et al., 2009; Pugh, Kiey, Milberg, & Lipsitz, 2003; Raz, Rodrigue, & Acker, 2003). This may be due to a specific vulnerability of prefrontal regions to aging and vascular disease (Gunning-Dixon & Raz, 2000). Executive functioning has further been associated with some aspects of physical functioning, especially gait speed, mobility, and falls (Ble et al., 2005; Coppin et al., 2006; Vergheese et al., 2002; Yogev-Seligmann, Hausdorff, & Giladi, 2008, but see also Chen, Peronto, & Edwards, 2012). These findings suggest that executive functioning may play a specific role in physical functioning and be particularly sensitive to cardiovascular burden.

The goal of this study was to examine the contribution of physical functioning and cardiovascular burden to the cognitive performance of community-dwelling older adults. A theoretically driven approach was chosen in order to create composite scores that represent three main cognitive domains: memory, processing speed, and executive functions. Several performance-based tests were also used to assess physical functioning. Our hypotheses were that physical performances would be associated with cognitive performances, and that executive function would be more strongly related to physical functioning than other cognitive domains. It was also predicted that cardiovascular burden would be related to cognitive functioning.

**Method**

**Participants**

One hundred and twenty-seven community-dwelling individuals aged 60 years and older were recruited from public advertisements or the center’s database where the research took place. Participants were enrolled in an intervention trial involving cognitive and physical exercise training. To address our specific research hypotheses, only the baseline assessments are reported here. A telephone-screening interview was used to assess the eligibility of each candidate.
Based on this first contact, participants were excluded if they reported one of the following elements: A history of neurological disease or major surgery in the year preceding the study; auditory or visual impairments that are not corrected; smoking; or severe mobility limitations. Participants who presented evidence of depressive symptoms (Geriatric Depression Scale [GDS] score ≥ 11) or cognitive impairment (Mini-Mental State Examination [MMSE] score ≤ 24) were further excluded, leaving 103 participants in the final sample. The ethical review board of the medical institution where the study took place approved the study. All participants provided informed written consent.

**Protocol and Measures**

Participants took part in three evaluation sessions within a 2-week interval. The medical evaluation and baseline cognitive screening measures were collected in the first session. Participants completed the neuropsychological assessments in the second session. Physical functioning tests took place in the third session.

**Medical Evaluation**

Participants completed an exhaustive medical assessment conducted by a geriatrician. The presence or absence of the following medical conditions was identified based on medical history and clinical evaluation: Hypertension, diabetes, dyslipidemia, angina, heart failure, arrhythmia, myocardial infarction, valvular disease, stroke or transient ischemic attack (TIA), thyroid problems, asthma, chronic obstructive pulmonary disease, pulmonary embolism, arthritis, osteoporosis, fractures, and number of medications. Body mass index (BMI; kg/m²) and waist circumference were also measured. According to World Health Organization, a BMI ≥ 30 kg/m² and waist circumference ≥102 cm for men and ≥88 cm for women are associated with increased CVR (WHO, 2008). Participants were classified as having abnormal BMI or waist circumference according to these cutoff points. Cognitive screening measures included a screening instrument used to assess global cognition and to detect signs of dementia (MMSE; Folstein, Folstein, & McHugh, 1975), a measure of verbal concept formation (Similarities subtest of the Wechsler Adults Intelligence Scale III [WAIS-III]) and a measure of short-term and working memory (Digit Span subtest of the WAIS-III). Finally, participants completed the GDS (Yesavage, 1988) and an audition/vision screening questionnaire.

**Neuropsychological Evaluation**

Neuropsychological assessments targeted episodic memory, processing speed, and executive functions. Processing speed was assessed with the Digit Symbol Substitution (DSS) subtest of the WAIS-III. In this test, participants had to associate symbols to numbers (1–9) by referring to a response key. They must complete as many items possible in 120 s. Memory was assessed with the Rey Auditory-Verbal Learning Test (RAVLT). It consisted of five presentations followed by recalls of a 15-word list, and one presentation and recall of a second 15-word list, immediately followed by a sixth recall trial of the first list. Thirty minutes following this learning phase, a delayed recall of the first list was performed. During the recognition phase of this test, participants had to recognize the 15 words of the first list among distractors. Executive functioning was evaluated with the Color-Word Interference Test (CWIT) of the Delis–Kaplan Executive Functions System (D-KEFS), the Trail Making Test (TMT), and the Baddeley Dual-Task (BDT). The CWIT is based on the Stroop procedure and includes four conditions: (a) In the color naming condition, participants had to name the color of rectangles (blue, green, and red); (b) in the reading condition, participants were asked to read color words printed in black ink; (c) the inhibition condition required participants to inhibit reading the words in order to name the incongruent ink colors in which the words are printed; and (d) in the switching condition, participants were asked to alternate between naming the incongruent ink colors and reading the words. This latter condition assessed both inhibition and cognitive flexibility. Time to complete each condition and number of errors were recorded. In part A of the TMT, participants were asked to link circled numbers (from 1 to 25) in serial order with a continuous line as quickly as possible. In part B of the TMT, participants had to link the circles by switching between letters and numbers (1-A-2-B-3-C, etc.) as fast as they could. The total number of errors was also recorded in each condition. The BDT was used to assess attention-sharing abilities. This test is composed of two tasks performed alone, then together: (a) A cancellation task in which participants had to trace as many Xs as possible in 120 s by following a specific pattern and (b) a short-term memory task in which they had to repeat digits in serial order during 120 s. A dual-task index was computed using the procedure suggested in the scoring manual. A higher score indicated greater dual-task interference. A negative score indicated a better performance in the dual-task condition than in the single task conditions.

**Physical Function Assessment**

The physical assessment included the following tests and measures. Gait speed was assessed with the 6-minute Walk Test (6-MWT). Participants were asked to walk the longest distance possible (recorded in meters) in 6 min. Functional capacities were assessed with the modified Physical Performance Test (PPT). The test included nine tasks rated from 0 to 4 points, for a maximum score of 36. Seven tasks were timed: 15 m walk, put on and remove a coat, pick up a coin on the floor, stand up from a chair (5 times), pick up a heavy book from a shelf, climb 9 stairs and standing balance with feet side-by-side, and semitandem and tandem positions. The other two tasks were performing a 360° turn and climbing up and down four flights of stairs. The
Timed Up and Go (TUG) is a marker of functional mobility in older adults (Podsiadlo & Richardson, 1991) and can help predicting risk of falls (Shumway-Cook, Brauer, & Woollacott, 2000). In this test, participants had to stand up from a chair, walk 3 m in a straight line, then around a cone, and 3 m back to sit back down on the chair, as quickly as possible. Grip strength was assessed with a hand-held dynamometer. The best of three trials with the dominant hand was recorded. Maximum chair stands in 30 s was used as a proxy of lower extremity strength.

Statistical Analyses

Computation of composite scores.—The neuropsychological battery assessed three cognitive domains: Memory, speed of processing, and executive functioning. All cognitive scores were first transformed in standardized \( z \)-scores and then averaged to provide a composite score. The Memory score included the following components from the RAVLT: Total number of words recalled in the 5 trials, immediate recall after interference, delayed recall, recognition, and false recognitions. The Speed score included DSS score, time to complete color naming and reading conditions of the CWIT, number of Xs in the single cancellation task of the BDT, and time to complete part A of the TMT. Finally, the Executive score included time to complete inhibition and switching conditions of the CWIT, total number of errors produced in the inhibition and switching conditions of the CWIT, and time to complete part B of the TMT. The dual-task index of the BDT was not included in the Executive composite score because many participants did not show the expected dual-task interference (negative or near 0 scores). \( z \)-scores of timed tests were multiplied by −1 so that a larger \( z \)-score represents a better performance.

The composite functional score represents the mean of the standardized \( z \)-scores of all physical performance measures: 6MWT, PPT, TUG, grip strength, and chair stands. Here again, \( z \)-scores of timed tests were transformed so that a larger \( z \)-score represents a better performance.

Eleven of the medical conditions assessed are known to exert a deleterious effect on cardiovascular function or are considered to be risk factors for cardiovascular disease: Hypertension, diabetes, dyslipidemia, angina, heart failure, arrhythmia, myocardial infarction, valvular disease, stroke/TIA, abnormal BMI, and abnormal waist circumference. As suggested by Song, Mitnitski, and Rockwood (2005), an index CVR variable was computed to reduce the number of dimensions studied. Thus, the CVR score represents the cumulative number of above-listed conditions present for each participant.

We performed Pearson’s correlations between the measures included in each composite score (see Supplementary Tables 3–6). Each correlation is significant and the large majority of them are moderate (.30–.50) or high (.50 and more), except for the correlation between grip strength and PPT in the Functional composite score (.17). We also computed Cronbach’s alphas to examine the internal consistency of the composite scores. Results show that each score has a strong reliability: Memory score: \( \alpha = .877 \); Speed score: \( \alpha = .791 \); Executive score: \( \alpha = .806 \); Functional score: \( \alpha = .826 \).

Multiple Regression Analyses

Multiple hierarchical linear regression analyses were performed to examine whether functional measures and/or CVR factors were associated with cognitive performance in three domains: Memory, processing speed, and executive functioning. Age, years of education, and sex were introduced in a first block of independent variables because these variables are known for their relationship with cognitive performance (see Supplementary Table 7 for correlations between demographic variables and composite scores). The composite Functional score was then added in a second block to assess its relationship with the three outcomes when age, education, and sex were controlled for. The third block included the CVR score to determine whether this factor explains additional variance in the model. For each block, the significance of the variation of \( F \) is considered to see if each set of independent variables explains a significant proportion of the variance. The magnitude of the standardized beta coefficient is also considered in order to understand the relative contribution of each independent variable in explaining our dependant variables.

Results

Ten participants had incomplete data, which made it impossible to compute composite scores. Hence, the analyses were conducted on the remaining 93 participants (66 women, 27 men; mean age = 71.8 ± 7.1; mean years of education = 14.7 ± 3.4). Values greater than 2.5 standard deviations (SD) on timed cognitive measures (four conditions of the CWIT and two conditions of the TMT) and on all physical tests were replaced by the mean + 2.5 SDs (see Supplementary Tables 1 and 2 for descriptive statistics of neuropsychological, physical, and medical variables). This method is suggested by Field (2009) to normalize the distribution while preserving the position of the score in the distribution. Across all participants, only 18 measures out of a possible 1,023 were outliers and were replaced using this procedure.

Table 1 presents summary results of the hierarchical regressions involving the three neuropsychological scores as dependant variables. Age, education, sex, Functional score, and CVR score were included as independent variables in three successive blocks.

Age, education, and sex explained 27% of the Memory score (\( p < .001 \)). Neither the Functional score nor the CVR score explained additional variance in the model (\( p = \text{ns} \)). For the Speed score, age, education, and sex explained
23% of the variance (p < .001). Interestingly, inclusion of the Functional score in the model explained an additional 15% of the variance (p < .001). However, CVR score did not explain additional variance in the Speed score (p = ns). As for the Executive score, age, education, and sex explained 19% of the variance (p < .001). As expected, the addition of the Functional score explained more variance for a total of 33% (p < .001). CVR score was not significantly associated with the Executive score (p = ns).

Regression coefficients (shown in Table 2) reveal that education and sex were significantly associated with the Memory score (education: β = .244, p = .012; sex: β = -.505, p < .001). The Functional score and the CVR score were not significantly related to memory performance in this sample (p = ns). As for the Speed score, it was significantly associated with sex (β = -.274, p = .005) as well as the Functional score (β = .509, p < .001). However, the Functional score showed the strongest relationship with the Speed score, as revealed by the larger standardized beta coefficient. The Executive score was associated with sex (β = -.243, p = .015) and the Functional score (β = .557, p < .001). Once again, standardized beta coefficients indicated that the Functional score was more strongly related to the Executive score than to sex. CVR score appears to be unrelated to the three cognitive scores, as revealed by the non-significant standardized beta coefficients. Each relation involving sex suggested better performance in women compared with men.

**Discussion**

The goal of this study was to examine the relationship between physical functioning and cardiovascular burden on memory, processing speed, and executive functioning in a sample of 93 community-dwelling older adults. Results showed that higher level of physical functioning was significantly associated with greater processing speed and better executive functions but was not associated with memory performance. These relations were independent of age, sex, and level of education. None of the cognitive domains were significantly associated with cardiovascular burden in this sample.

Other studies have reported that some aspects of physical functioning are associated with cognitive performance. Longitudinal studies conducted with healthy older adults showed that cognitive impairment was preceded by slowing of gait speed and/or tapping speed (Buracchio et al., 2010; Camicioli, Howieson, Oken, Sexton, & Kaye, 1998; Deshpande, Metter, Bandinelli, Guralnik, & Ferrucci, 2009; Marquis et al., 2002). Some studies found that weaker muscle strength was related to poorer general cognition (Alfarro-Acha et al., 2006; Taekema et al., 2010) and higher risk of mild cognitive impairment and dementia (Boyle et al., 2009). In the Health, Aging and Body Composition Study, all tests of motor performance (walking, standing balance, and chair stands) were significant predictors of cognitive performance, with a stronger relation with psychomotor speed (DSST) compared with global cognition (Teng-modified Mini-Mental Status Exam [3MS]; Rosano et al., 2005). In this study, we further extended the range of cognitive functions and physical parameters to better represent the complexity of physical functioning and the specificity of cognitive functions. In line with Rosano and coworkers’ findings, we observed that a score of physical functioning, which includes various performance-based tests of physical capacities, is associated with performance in tests of processing speed. Indeed, many physical tests in our battery were timed and required psychomotor coordination,
as did most of the neuropsychological tests included in the Speed score. In this study, the model including demographic variables and the Functional score explained 38% of the variance of processing speed and 33% of the variance of executive performance. Importantly, the physical functioning score explained a significant amount of additional variance after demographic variables were accounted for (15% for speed of processing and 14% for executive functioning), and both cognitive domains were more strongly associated with physical performance than with any other variable.

Processing speed is involved in various activities in everyday life, such as driving (Edwards et al., 2009), and thus can contribute in preserving independent functioning in older age. Moreover, the prediction of executive functioning is of paramount importance because these frontally mediated mechanisms play a crucial role in independent functioning in the older population. In fact, a growing body of research has identified a specific relationship between executive functioning and IADL (e.g., taking medication, managing money, doing housework, etc.), a widely used measure of functional status in older adults. Cross-sectional and longitudinal studies have shown that executive impairment was a significant predictor of lower IADL performance, independently of age, education, and medical factors (Cahn-Weiner et al., 2000; Carlson et al., 1999; Johnson et al., 2007; Royall, Palmer, Chiodo, & Polk, 2004). Executive functions thus appear to be important markers of functional status in late life, beyond sociodemographic and health-related factors. This highlights the importance of predicting changes in executive functioning in the older population.

The parallel evolution of cognitive and physical functioning in older adults population has led some researchers to suggest a common cause for both types of decline (Christensen et al., 2001). Yet, the current state of knowledge does not allow for the identification of specific biological mechanisms responsible for both cognitive and physical impairments, neither a direct causal pathway, in either direction, between them. However, it is likely that age-related changes in the central nervous system, such as reduced white matter integrity or cerebrovascular damage may underlie physical and cognitive dysfunction. Some brain regions have also been identified as being more sensitive to age-related decline. In particular, prefrontal regions that play an essential role in the efficacy of executive functions (Stuss & Alexander, 2000) show larger decrements with advancing age (West, 1996). This would partly explain the close link between executive functioning and functional capacities. Nonetheless, a large portion of older adults do not experience cognitive deficits in late life. Longitudinal studies that include brain-imaging data could help clarify the link between brain integrity, physical functioning, and cognitive performance and further identify moderators of decline.

Previous studies have demonstrated a relationship between CVR factors and cognitive functioning (Duron & Hanon, 2008; Knopman et al., 2001). The lack of such association in this study can be explained by methodological and conceptual factors. Firstly, most of our participants were relatively healthy and had no or only a few CVR factors or diseases. This may have limited the chance of finding significant associations. Secondly, the effect of each cardiovascular factor on cognition may differ. By choosing a nonweighted method for the computation of cardiovascular factors, we may have overlooked some important distinctions in the relative influence of each medical condition on cognitive performance. Some conditions, such as diabetes and hypertension, appear to be stronger independent predictors of cognition (Duron & Hanon, 2008; Kuo et al., 2005) than others, such as elevated waist circumference (Chu et al., 2009; Dore, Elias, Robbins, Budge, & Elias, 2008), which was very prevalent in our sample. Yet, they all contributed equally to the total score. Thirdly, the evaluation of CVR factors and diseases was done in a dichotomous manner (presence vs. absence). This method did not allow assessing multiple important parameters, such as duration of the illness, degree of control by medications, or markers of severity (e.g., actual blood pressure, levels of cholesterol, etc.). Perhaps the identification of an association between CVR factors or diseases and subtle cognitive deficits in a healthy older adult sample requires a more detailed assessment of medical status. Nevertheless, our results are not totally unexpected given that other studies have identified a relationship between physical and cognitive functioning independently of comorbid medical conditions (Rosano et al., 2005), even in frail older persons (Langlois et al., 2012). This suggests that the association between physical functioning and cognition persists even when cardiovascular burden is accounted for. Future research should examine the relationship between specific parameters of disease (duration, severity, medication, etc.) and cognitive functioning.

The novel contribution of this study was to extend the comprehension of the relation between physical functioning and cognitive performance by demonstrating that a collection of simple performance-based tests of physical functioning was specifically associated with processing speed and executive functioning in a sample of independently living older adults. This issue is not trivial considering the importance of speed and executive functioning in the ability to perform everyday activities, such as driving, preparing a meal, managing finances, etc. Importantly, the identification of such an association between tests of physical performance and cognition suggests that enhancing physical capacities through physical training may improve cognitive functioning. Moreover, the physical tests used in our battery are simple to administer and could be easily implemented in clinical settings to detect persons at risk of cognitive deficits. Longitudinal studies involving brain
imaging are required to determine the direction of causality between physical and cognitive functioning and identify shared biological markers of decline.

**Supplementary Material**

Supplementary material can be found at: http://psychosocgerontology.oxfordjournals.org/.

**Funding**

This work was supported by a Canadian Institutes of Health Research (CIHR) grant (#187596). L. Desjardins-Crépeau was supported by a doctoral fellowship from the CIHR and L. Bherer was supported by the Canadian Research Chair Program.

**Acknowledgments**

We would like to thank Dr Christine Gagnon for statistical and editorial support as well as Dr Sarah Fraser for helpful comments and edits.

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