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PRONOUNCEMENT

Daily Step Counts for Measuring Physical Activity Exposure and Its Relation to Health

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ABSTRACT

KRAUS, W. E., K. F. JANZ, K. E. POWELL, W. W. CAMPBELL, J. M. JAKICIC, R. P. TROIANO, K. SPROW, A. TORRES, and K. L. PIERCY, FOR THE 2018 PHYSICAL ACTIVITY GUIDELINES ADVISORY COMMITTEE. Daily Step Counts for Measuring Physical Activity Exposure and Its Relation to Health. *Med. Sci. Sports Exerc.*, Vol. 51, No. 6, pp. 1206–1212, 2019. **Purpose:** A systematic primary literature review was conducted to evaluate the relationship of physical activity—as measured by daily step counts—with all-cause mortality, cardiovascular disease mortality, incident cardiovascular disease, and type 2 diabetes mellitus; to evaluate the shape of dose–response relationships; and to interpret findings in the context of development of the *Physical Activity Guidelines for Americans, Second Edition*. **Methods:** A primary literature search encompassing 2011 to March 2018 for existing literature reporting on these relationships was conducted. **Results:** Eleven pertinent articles were identified. Seven longitudinal studies examined the relationship between daily step counts and mortality, disease incidence, or risk. Two studies examined objectively measured steps per day and all-cause mortality; one was restricted to a relatively small elderly population. One study examined cardiovascular events, defined as cardiovascular death, nonfatal myocardial infarction, or nonfatal stroke. The other four longitudinal studies addressed incident type 2 diabetes. All longitudinal studies reported an inverse relationship between steps per day and outcome risk. In one study, 531 cardiovascular events occurred during more than 45,000 person-years of follow-up. Before intervention, each increment of 2000 steps per day up to 10,000 steps was associated with a 10% lower cardiovascular event rate. Also, for every increase of 2000 steps per day over baseline, there was an 8% yearly reduction in cardiovascular event rate in individuals with impaired glucose tolerance. **Conclusions:** Daily step count is a readily accessible means by which to monitor and set physical activity goals. Recent evidence supports previously limited evidence of an inverse dose–response relationship of daily steps with important health outcomes, including all-cause mortality, cardiovascular events, and type 2 diabetes. However, more independent studies will be required before these observations can be translated into public health guidelines. **Key Words:** ALL-CAUSE MORTALITY, CARDIOVASCULAR DISEASE PREVENTION, DIABETES PREVENTION, PHYSICAL ACTIVITY GUIDELINES

Since the release of the *2008 Physical Activity Guidelines Advisory Committee Report* (1), several new methods have emerged by which physical activity and exercise can be measured, quantified, and prescribed to individuals seeking exercise-associated health benefits. The proliferation and popularity of newly developed wearable devices, particularly those worn on the wrist or finger containing accelerometers, have facilitated the monitoring and goal setting for steps per day (see article on *Promotion of Physical Activity* in this issue— (2,3)). There are also some new methods (e.g., machine learning algorithms); however, these do not apply to how steps are estimated from a device. It is now possible to assess the contribution of light activity to step counts per day and therefore to estimate total daily physical activity energy expenditure. Because step counts incorporate both light and moderate-to-vigorous

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physical activity and counting steps has been become a common method of assessing daily physical activity, the Physical Activity Guidelines Advisory Committee (PAGAC;the Committee) considered it important to better understand how the measurement of steps per day might fit into the assessment of daily or weekly physical activity exposures and its relationship to important health outcomes in the context of development of the *Physical Activity Guidelines for Americans, Second Edition*.

For the *2018 Physical Activity Guidelines Advisory Committee Scientific Report* (4), the Committee chose to address one overall question and two subquestions regarding daily step counts, summarized as follows: 1) what is the relationship between step counts per day and all-cause and cardiovascular disease (CVD) mortality, CVD events, and type 2 diabetes? 2) is there a dose–response relationship, and if there is, what is the shape of the relationship? and 3) does the relationship vary by age, sex, race/ethnicity, socioeconomic status, or weight status?

METHODS

The overarching methods used to conduct systematic reviews informing the *2018 Physical Activity Guidelines Advisory Committee Scientific Report* are described in detail elsewhere (4,5). The searches were conducted using electronic databases (PubMed®, CINAHL, and Cochrane). An initial search conducted to identify systematic reviews, meta-analyses, and pooled analyses examining the relationship between step counts and various health outcomes did not identify sufficient literature to answer the research questions as determined by the Committee. Therefore, a complete *de novo* search of original research was conducted. The searches were conducted from inception until June 2017 for the 2018 PAGAC report; the search was expanded until March 2018 for this article. The searches were supplemented by asking Committee experts in the area to provide additional articles identified through their familiarity with the literature. Eligibility criteria were original research studies published in English; examining step counts as the physical activity exposure among adults; and health outcomes including all-cause or CVD mortality, incidence of CVD events, type 2 diabetes biomarkers, and incidence. Studies on individuals with existing CVD or high-performance athletes were excluded. The full-search strategy is available at https://health.gov/paguidelines/second-edition/report/supplementary_material/pdf/Exposure_Q4_Steps_Evidence_Portfolio.pdf.

Search terms included steps-specific terms combined with outcome-specific terms. Search term selection was difficult for this specific topic. The use of the terms "step," "stepping," and similar terms containing "step" is prevalent in the medical literature and would have resulted in an overwhelming number of irrelevant articles for review; therefore, based on some preliminary test searches, we restricted our search to articles containing the terms "step count," "steps per day," "daily steps," or "walking."

The titles and abstracts of the identified articles were independently screened by two reviewers. The full texts of relevant articles were reviewed to identify those meeting the inclusion criteria. Two professional librarians independently abstracted data and conducted a quality or risk of bias assessment using the USDA NEL Bias Assessment Tool (6). Discrepancies in article selection or data abstractions were resolved by discussion or by a third reviewer, if needed. The protocol for this review was registered with the PROSPERO database registration ID CRD42018092747.

RESULTS

Search Results and Study Characteristics

A literature tree summarizing the selection of literature for this review is contained in Supplemental Digital Content (see Figure, Supplemental Digital Content 1, Study Selection Literature Tree, http://links.lww.com/MSS/B539). The search strategy only yielded appropriate articles dating back to 2011. The committee reviewed evidence from 11 articles reporting on 7 original research studies (see Figure, Supplemental Digital Content 1, Study Selection Literature Tree, http://links.lww.com/MSS/B539). Of the 11 articles, 4 used a cross-sectional design (7–10), 6 used a prospective design (11–16), and 1 used a randomized controlled design where control and intervention groups were compared, as well as pooled, to examine steps per day with respect to insulin resistance (17). The NAVIGATOR study, a multicenter trial of 9306 individuals with impaired glucose recruited from 40 countries, provided four articles (three longitudinal and one cross-sectional). Since the four-cell two-by-two randomized design examining the effects of two pharmacologic agents on cardiovascular events and progression to type 2 diabetes was null for significant clinical drug effects (18,19), all four NAVIGATOR articles examined the relationship of daily steps to health outcomes after pooling drug intervention and control groups. Therefore, the NAVIGATOR study contributed one cross-sectional (10) and three longitudinal studies (12,15,16), depending on the analytic approach. Participants in all 11 reviewed studies were middle-age or older. Supporting the generalizability of conclusions, men and women, multiple races and ethnicities, a continuum of body sizes, and diverse geographical areas were represented.

Cross-sectional studies cannot control for bidirectional relationships—the outcome causing the exposure as well as the exposure causing the outcome. Because it is likely that individuals with undiagnosed disease may take fewer steps per day than healthy individuals, the reviewed cross-sectional studies were used only to understand usual step counts per day across sample populations and not for primary evidence for relationships.

The longitudinal studies reported health outcomes including all-cause mortality (11,14), a composite of CVD incidence, which included cardiovascular death, nonfatal myocardial infarction, or nonfatal stroke (16), metabolic syndrome (12), and blood glucose concentrations—the latter two as biomarkers of progression toward diabetes mellitus (13,15,17).

The baseline number of steps per day varied across studies, but the median was approximately 5000 steps per day. In one report (17), 80% of the steps taken in a day were of light-intensity physical activity. Cohorts of older adults accumulated fewer daily steps than did middle-age adults. An Australian cohort of Tasmanian adults (mean age at baseline, 50 yr) (13) accumulated nearly twice as many daily steps at baseline as other samples—approximately 10,000, whereas most study baseline steps per day were approximately 5000.

Evidence on the Overall Relationship

Daily step counts and all-cause mortality. Dwyer et al. (11), observing 219 deaths in 2576 residents of Tasmania over 10 yr of follow-up, studied the relation of daily step counts and mortality. The mean age of the population was 58.8 yr. Mean daily step counts were 8781 ± 4538 for men and 8925 ± 8925 for women. Greater daily step counts were inversely and linearly associated with all-cause mortality: adjusted hazard ratio 0.94 (confidence interval, 0.90, 0.98) per 1000 daily steps. In a mean of 3.7 yr of follow-up in repeated assessment, changing from sedentary to 10,000 daily steps was associated with 46% less mortality risk over the ensuing decade when adjusted for baseline daily step counts and other mortality risk factors.

Yamamoto et al. (14) studied 419 physically independent, community-dwelling 71-yr-old elders in Japan. Over a mean follow-up period of 9.8 yr, they observed 18% mortality (76 individuals). Groups were characterized by quartiles of steps per day (<4503, 4503–6110, 6111–7971, >7971 daily steps). Probably because of to the low study numbers, hazard ratios for mortality over the period were only statistically significant when comparing the greatest quartile of daily steps group with the least quartile of daily steps (hazard ratio, 0.46; confidence interval, 0.22–0.96).

Daily step counts and cardiovascular events. Several longitudinal studies examined the relationship between daily step counts and disease incidence or risk. One study examined the relationship of daily step counts to cardiovascular events, defined as cardiovascular death, nonfatal myocardial infarction, or nonfatal stroke in a population at risk for type 2 diabetes (16). This study included more than 45,000 person-years of follow-up in which 531 cardiovascular events occurred. Both baseline daily steps and change in daily steps were inversely associated with risk for cardiovascular events. Compared with the baseline step count, each 2000-daily-step increment up to 10,000 steps was associated with a 10% lower cardiovascular event rate. Also, for every 2000-daily-step increase, there was an 8% yearly reduction in cardiovascular event rate (Fig. 1). This report provides evidence of the benefit of increasing steps per day to reduce cardiovascular event incidence. The relationship can be modeled as a linear relationship (Fig. 2).

Dose–Response

Each of these dose–response relations seemed to be linear across the ranges of daily steps and change in daily steps. The linear relationships and effect sizes approximate those observed by Dwyer et al. (11) in a nondiseased population.

Daily step counts, metabolic syndrome, and type 2 diabetes incidence. Using NAVIGATOR data, Huffman et al. (12) observed a relationship of daily steps with metabolic syndrome score: for every incremental of 2000 greater baseline daily steps, there was a 29% reduction in the 6-yr metabolic syndrome score. Ponsonby et al. (13) estimated that for any average daily step count, additional 2000 steps were associated with a 25% reduction in incidence of dysglycemia over the succeeding 5 yr. Similar to the NAVIGATOR studies (12,16), the relationship between daily step count and health outcome seemed linear in Ponsonby et al. (13).

In a study published just after the search date for this article, Kraus et al. (21) reported on the relationship of baseline daily step counts and incident type 2 diabetes in the NAVIGATOR

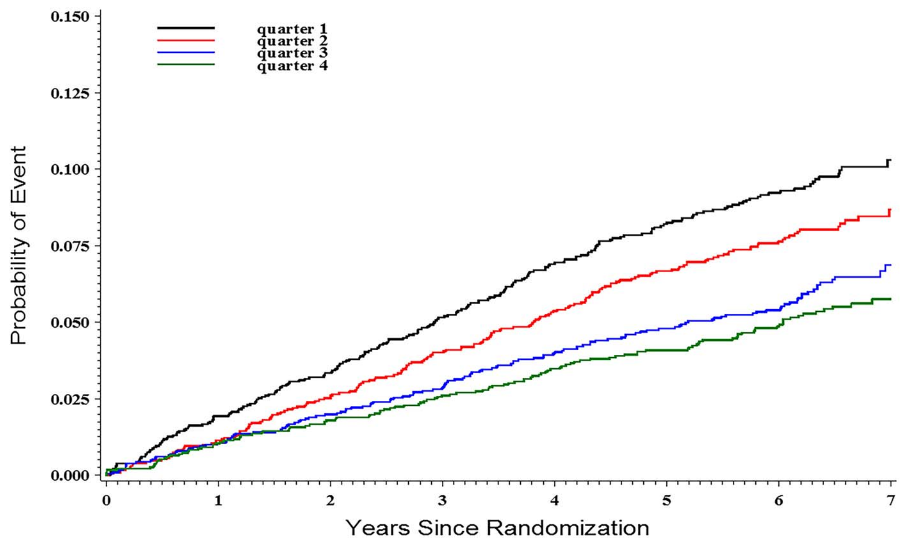

FIGURE 1—Kaplan–Meier survival curves for the death, myocardial infarction, and stroke composite outcome by quartiles of steps per day (16). Survival distributions were compared using log-rank test ($P < 0.0001$). Individuals at risk at each year of follow-up were as follows: 9306 (Y0), 8930 (Y1), 8659 (Y2), 8355 (Y3), 8008 (Y4), 7660 (Y5), 6244 (Y6), and 1505 (Y7). Quartiles of daily steps were as follows (means (range)): 2006 (859–2859), 4659 (4085–5216), 7093 (6382–7754), and 10569 (9447–12299). Figure developed from data in Refs. (16, 20).

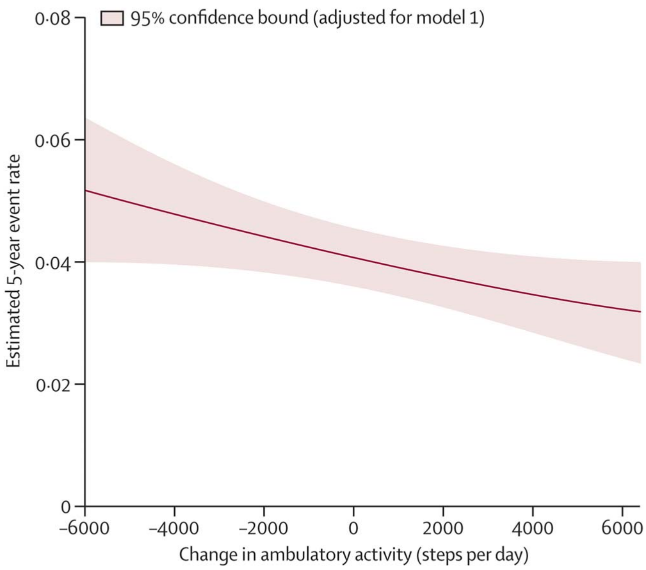

FIGURE 2—Association between change in steps per day and cardiovascular events in individuals with impaired glucose tolerance (16). The association between change in daily ambulatory activity and cardiovascular events in those with impaired glucose tolerance: cohort analysis of the NAVIGATOR trial. Reproduced with permission from Yates T, Haffner SM, Schulte PJ, et al. Association between change in daily ambulatory activity and cardiovascular events in people with impaired glucose tolerance (NAVIGATOR trial): a cohort analysis. *Lancet*. 2014;383(9922):1059–66. Copyright © 2014 Elsevier Ltd. All permission requests for this image should be made to the copyright holder.

study. Pedometer data were obtained on 7118 participants, and 35% developed diabetes. In an unadjusted analysis, each 2000-step increment in the average number of daily steps up to 10,000 was associated with 5.5% lower risk of progression toward diabetes (hazard ratio, 0.95; 95% confidence interval, 0.92–0.97), with a >6% relative risk reduction after adjustment. This relationship also seems linear.

Demographic factors and weight status. The risk reduction for incident cardiovascular events reported in NAVIGATOR was not affected by weight status, sex, age, geographical region, or level of baseline steps per day (16). Negative associations between daily steps and metabolic syndrome score reported in NAVIGATOR were independent of weight status (12). Ponsonby et al. (13) reported associations that were also independent of weight status when examining daily steps and dysglycemia. Thus, for studies evaluating effect modification by demographic or weight status, none were found. Despite these findings, the evidence on these factors was not sufficient for the Committee to draw a conclusion about any relationship.

DISCUSSION

The 2018 PAGAC report (4), strengthened by recently published research (11,14,21), supports using daily step count as a viable metric for assessing the association of physical activity with CVD events, type 2 diabetes mellitus onset, and all-cause mortality.

There is a striking contrast between the linear relationship of steps with mortality, CVD, and type 2 diabetes when compared with the rapidly negative curvilinear relationship of moderate-to-vigorous physical activity for these same health outcomes (see an article in this by Kraus et al. (20)). This contrast raises the question as to whether the apparent linear relationship of daily steps with the measured health outcomes is due to the contribution of light-to-moderate habitual daily activities. There are other possible explanations for this contrast between the shapes of the curves for step counts and moderate-to-vigorous physical activity on mortality. For example, measurement error, wear time, and other factors can affect the data gathered by physical activity trackers (3). That said, very low exposures—those with relatively few daily steps—contribute to reduced disease risk, albeit to a lower extent or with less impact than even a small amount of moderate-to-vigorous physical activity. Certainly, light activity contributes to reduction in disease risk (22). These issues will need to be sorted out with more research.

Finally, it remains unclear how many steps provide the optimal health benefit for the general population and for specific health benefits for those with existing disease. The traditional 10,000 step target already is being adopted by some countries (23) as a national public health goal. Is this the right number? Populations around the world are experiencing both increases in sedentary time (24) and decreases in habitual daily physical activity (25). Estimates that current moderate-to-vigorous physical activity guideline targets constitute 3000 to 6000 daily steps (26,27), when added to spontaneous "background activity" of 2500 to 5000 steps, might suggest that one should aim for more than 10,000 steps per day as a public health target to counteract the effects of increasing sedentary time (24,28).

A specific example might be helpful. A sedentary individual finds that she uses 5000 steps per day in normal daily activity. She measures the number of steps in a 10-min brisk (moderate-intensity) walk to be 1000 steps. Therefore, she finds she can meet the US physical activity guidelines for brisk walking of 150 $\min\cdot wk^{-1}$ by adding approximately 2000 brisk walking steps per day to her baseline activities of daily living—or aim for 7000 steps per day, of which 20 $\min\cdot d^{-1}$ is in the form of her daily walk. Pertinently, a 2011 position stand from the American College of Sports Medicine recommends that adults obtain at least 7000 steps per day (29).

However, there is at least one cautionary note. For some populations, 10,000 daily steps might have harmful effects. Limited data suggest a possible progression of osteoarthritis at step count per day greater than 10,000 (see also an article in this issue by Kraus (30)). However, as argued earlier, these step counts per day do not exceed those equivalent to the current physical activity guidelines.

Daily step counts are a readily accessible means by which to monitor and set physical activity goals (see an article on physical activity promotion in this issue (2)). In this review, we point to emerging evidence of a linear inverse dose–response relationship of daily steps with important health outcomes, including all-cause mortality, cardiovascular events, and type 2 diabetes. However, more evidence will be required before these observations can be translated into public health guidelines.

Public health impact. Steps are a basic unit of locomotion and as such provide an easy-to-understand metric of ambulation—an important component of physical activity. Measuring daily step counts can motivate diverse samples of individuals to increase physical activity levels (see the physical activity promotion article in this issue (2)). Increasingly, the self-assessment of steps can be accomplished through objective, readily obtainable technology with physical activity trackers, particularly those worn on the wrist or finger. Unlike the measure of moderate-to-vigorous physical activity in minutes per week or weekly energy expenditure (e.g., MET-minutes), the metric of *step counts per day* provides a comparable denominator to how dietary energy intake in most dietary guidelines is standardized—*per day*. As a result, daily steps counts might provide a useful tool for researchers and the public to address a variety of health and physical activity issues. In addition, steps can be at light-, moderate-, and vigorous-intensity levels, providing a range of exertion choice to promote walking at all ages and for all levels of fitness in the context of physical activity monitoring and prescription. For these reasons, measuring of daily step counts has the potential to significantly improve the translation of research findings into public health recommendations, policies, and programs.

Evidence statements. Because four of the originally reviewed studies were derived from one study—the NAVIGATOR trial, containing generally older individuals where the generalizability of the findings is suspicious—the Committee originally determined that there was insufficient evidence available to determine whether a relationship exists between steps per day and all-cause and CVD mortality. The grading of the accumulated evidence is available in Supplemental Digital Content 2 (see Table, Supplemental Digital Content 2, evidence statements for conclusions, http://links.lww.com/MSS/B540). However, in the interim, two new articles have come to our attention supporting the relationship between step counts per day and mortality (11,14). The Committee determined that there was limited evidence suggesting that daily step counts are associated with reduced incidence of CVD events and risk of type 2 diabetes. In the interim, one new article has been published supporting the relationship of step counts per day and type 2 diabetes incidence (21); however, this finding was from only one study—the NAVIGATOR trial—and more evidence may be required to change this strength of evidence determination. The Committee determined that there was limited evidence suggesting a dose–response relationship between the measure of steps per day and CVD events and type 2 diabetes risk. However, there are new dose–response data in this report demonstrating a linear relation of step counts per day with all-cause mortality, CVD events, and type 2 diabetes. Finally, the Committee determined that there was insufficient evidence available to determine whether the relationship between the measure of daily step counts and CVD events and type 2 diabetes risk is influenced by age, sex, race/ethnicity, socioeconomic status, or weight status. Thus, although the evidence base supporting the use of daily step counts as a metric for physical activity with respect to its effect on health outcomes is growing, and new evidence supports the previously determined limited evidence, still there is much work to be done before it can be fully adopted.

Needs for future research. Despite a developing literature on the relation of daily step counts and important health outcomes, there remains an insufficient literature to support using this metric as a public health metric for monitoring physical activity exposure. Given this, more research is needed in the following areas.

Advance the understanding of daily step counts and health in research addressing the equivalency of steps per day measured using various devices. Rationale: Peripheral activity monitoring devices include spring-suspended lever arm pedometers, accelerometers converting movement count or gravitational constant data to steps per day, three-dimensional accelerometer-based activity trackers, and smartphone–based mobile applications using internal accelerometers. However, with ever increased interest in personalized health monitoring and more options becoming increasingly available over time, without equivalency research, dose–response understandings will be specific to each device. In addition, newer devices, which more finely parse data, are likely to provide more sensitive metrics for capturing health-related walking behavior—for instance, intensity of steps per day, average stepping rate per day, and stepping cadence. Conversely, advances in daily step count research will inform decisions by product engineers and consumers as to what features are most useful in personalized health monitoring.

Develop more information on the metrics of daily step counts useful for understanding the relationship of steps per day with health outcomes, develop more understanding of the relation of pedometer-measured and accelerometer-measured steps per day, and explore the relationship between stepping cadence and health. This foundational information is critical to understanding how we might use legacy data—such as from National Health and Nutrition Examination Survey, where steps per day data were collected using accelerometers—to develop more detailed information on the relations of daily step counts to health outcomes. Such information will also permit subject-level pooling studies to increase sample sizes by harmonizing pedometer-collected data and accelerometer-collected data. Also requiring more work is the relationship of steps counts measured by pedometer to that of light activity/steps counts measured with accelerometers—not used in this report—and the association of step cadence (measured so far using only accelerometers) with health outcomes (31). Recently, the Consumer Trade Act provided guidelines for all new consumer monitors to meet for quantifying steps per day. This will be useful for getting better consistency between devices and future studies.

Conduct additional longitudinal research in the form of either prospective studies or randomized controlled trials to examine the dose–response relationship between daily step counts and health outcomes. This information is critical for setting target volumes of physical activity using steps per day as a metric for predicting the incidence of future disease outcomes. In this review, only one randomized controlled trial was identified, and it did not include multiple arms to examine the effects of various doses of steps per day on outcomes.

Include measurement methods in prospective and randomized controlled studies examining whether the rate of stepping and bout lengths of continuous stepping influence the relationship between steps per day and disease outcomes. The studies reviewed used simple physical activity trackers providing accumulated steps and could address neither patterns nor intensity of steps. Additional physical activity assessment methods allowing for these data should provide a better target for recommending physical activity volume and effective means for meeting steps per day targets.

Develop more understanding of the relation of individual characteristics—age, sex, infirmity, and disease status—serve as effect modifiers of the relationship of daily step counts and health status. The economy of movement varies by age; walking cadence varies by age; and disease states can influence cadence, energy efficiency, and the safe parameters associated with walking. Therefore, much more information ultimately will be needed before public health and clinical recommendations can be made about the relationships of daily step counts and human health.

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HHS staff provided general administrative support to the Committee and assured that the Committee adhered to the requirements for Federal Advisory Committees. HHS also contracted with ICF, a global consulting services company, to provide technical support for the literature searches conducted by the Committee. HHS and ICF staff collaborated with the Committee in the design and conduct of the searches by assisting with the development of the analytical frameworks, inclusion/exclusion criteria, and search terms for each primary question; using those parameters, ICF performed the literature searches.

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