and early 1950s it was widely believed that we were a long way from solving the polio problem, if ever. However, Dr. Jonas Salk's discovery of the polio vaccine, and the classical epidemiological studies by Bodian, Paffenbarger, and others led to the first successful polio vaccine trial in the mid-1950s. Dr. Paffenbarger published numerous papers on infectious disease, including the classical papers on poliomyelitis.[1, 4, 5, 20, 41, 43, 45, 46, 53-55, 68]

Dr. Paffenbarger continued his work on infectious diseases during 1955-1958 while he was assigned to the Robert A. Taft Sanitary Engineering Center in Cincinnati. He also turned his attention to parapartum mental illnesses, completing important research and publishing several papers on the topic.[42, 44, 51, 52]

Dr. Paffenbarger's assignment in the Public Health Service took him to the National Heart Institute (now the National Heart, Lung, and Blood Institute) in 1958. Although he continued research on topics such as mental illnesses, suicide, and accidental death, he soon began working on projects to help understand the new major public health problem of cardiovascular disease. He was one of the early investigators involved in the Framingham Heart Study, which laid the foundation for a great deal of cardiovascular disease epidemiology that followed over the next decades. It was during this time that Dr. Paffenbarger began to develop an interest in the possible role of physical inactivity in the development of cardiovascular disease. He would often talk about those early days and his conversations with individuals such as Dr. Paul Dudley White, the famous Boston cardiologist, and Dr. James Watt, the first Director of the National Heart Institute. He became aware of the first systematic research on physical activity and coronary heart disease conducted by Professor Jeremy ("Jerry") Morris of London, published shortly before Dr. Paffenbarger joined the National Heart Institute. He later met Professor Morris, and the two became great friends, and this friendship persisted throughout Dr. Paffenbarger's life.

Dr. Paffenbarger established two major epidemiological studies that led to the outstanding work on physical activity and cardiovascular disease during the 1960s: the College Alumni Health Study (including alumni from Harvard University [the Harvard Alumni Health Study] and the University of Pennsylvania) and the San Francisco Longshoremen Study. Both studies led to first-of-a-kind reports on topics such as physical activity and stroke,[49] hypertension,[59] diabetes,[17] and longevity.[47] His contributions to physical activity and health are discussed in more detail below.

Dr. Paffenbarger's Honors

Dr. Paffenbarger received many awards and honors over the years. They take three pages in his CV, and are too numerous to list here. Some of the awards most relevant to the physical activity epidemiology field are:

- The first International Olympic Committee Prize for contributions to sports medicine, shared with his friend Professor Jerry Morris. The prize was awarded in 1996 as part of the Olympic Games in Atlanta. The Gold Medal that accompanied this prize is displayed in the headquarters of the American College of Sports Medicine in Indianapolis.
- Honorary Order of the Horse Collar Knights, University of Kuopio, Finland. This order was established many years ago, and some of the world's most distinguished exercise scientists have been recipients. Dr. Paffenbarger always enjoyed going to the Puijo Symposium in Kuopio, where this honor was bestowed. The 20th Puijo Symposium will be held in June 2009, with a competition for the Ralph S. Paffenbarger, Jr. awards for the best scientific posters.
- American College of Sports Medicine (ACSM)—Citation Award and the ACSM's highest award, The Honor Award, were both won by Dr. Paffenbarger. He also delivered the 1988 Wolffe Lecture, which is the premier lecture at the ACSM annual meeting.

Influence on Present Contributions

Dr. Paffenbarger's contributions to epidemiologic research on physical activity and health are many and the ideas he initiated continue to impact the field today. Some of his ideas which have influenced contemporaneous research may be grouped into three themes carrying important public health implications – first, that physical activity has a wide range of effects for chronic disease prevention; second, that physical activity has health effects among many subgroups; and third, that dose-response relationships between physical activity and health are important.

Wide range of health benefits from physical activity for chronic disease prevention

When Dr. Paffenbarger initiated the College Alumni Health Study in the early 1960s, it was to investigate the predictors of coronary heart disease.[26] However, the study evolved to become one that primarily focused on a risk factor – physical inactivity – as opposed to focusing on a specific disease outcome

To that end, Dr. Paffenbarger developed a method of assessing physical activity via questionnaire, which has been extensively tested and shown to be reliable and valid[26] (including validation against doubly-labeled water,[6] a gold standard for measuring energy expenditure) for large population studies. Using this questionnaire, he examined the associations of physical activity with a wide range of outcomes, including longevity,[29, 47, 48] coronary heart disease,[34, 58] stroke,[32, 56] type 2 diabetes,[17] hypertension,[59] various site-specific cancers,[31, 33] Parkinson's disease,[36] peptic ulcer,[57] and depression and suicide.[50]

Contemporaneous research has continued on this theme, investigating the many health benefits associated with physical activity. In particular, there has been a great deal of interest in cancer prevention and survival[65] since cancer is a major cause of death in the world, and in preventing or delaying neurodegenerative diseases, which have been increasing in incidence commensurate with longer human lifespan today.[22]

An example of a study examining the role of physical activity in cancer prevention comes from the European Prospective Investigation into Cancer and Nutrition (EPIC) investigating pancreatic cancer,[2] which has been less well studied than colon, breast and prostate cancers.[27] Among the postulated mechanisms for an inverse relation between physical activity and risk of this cancer are the beneficial effects of exercise on insulin and glucose sensitivity, which are related to pancreatic cancer risk.[27] EPIC investigators reported a non-significant reduction in pancreatic cancer risk (relative risk, RR, =0.82; 95% confidence interval, CI, 0.50-1.35) with physical activity.[2] Other studies have reported inconsistent associations, and further research is needed.[27]

With regard to neurodegenerative diseases, several mechanisms may be responsible for the protective effect of physical activity on the brain, including improvement of cerebrovascular circulation, increased production of neurotropic substances, and decreased age-related neuronal loss and decline in spontaneous motor activity.[36] While epidemiologic data on the relation between physical activity and neurodegenerative diseases are limited, some studies have reported inverse associations.[22] For example, a Finnish study observed rates of dementia and Alzheimer's disease among regularly active persons that were less than half those among inactive persons (RR=0.48 [0.25-0.91] and 0.38 [0.17-0.85], respectively).[61]

Health benefits of physical activity observed in many subgroups

A second theme emerging from Dr. Paffenbarger's research is the investigation of whether the health benefits of physical activity extend to different subgroups of individuals.[58] In his early research, the examination of subgroups was probably motivated by the desire to assess confounding – that is, physically active individuals also are likely to possess other healthy habits and a better health profile.[28] Because of these potential differences, the question arises as to whether it is physical activity that is responsible for the lower rates of chronic disease, or whether the lower rates are due to other associated health characteristics.

Today, researchers have statistical methods to control for confounding, but continue to examine subgroups of individuals to investigate whether physical activity can benefit the health of, for example, men and women; older and younger persons; white individuals and persons of other racial/ethnic groups; leaner and heavier persons; and persons without and with a history of cardiovascular disease.[19, 62, 64]

One topic kindling continued debate is the relation of physical activity or fitness to health among subgroups of persons with differing adiposity (i.e., the "fit or fat" debate). Some studies suggest that physical activity/fitness can completely obliterate the increased risk of all-cause mortality or cardiovascular disease mortality associated with increased adiposity.[25] Other studies, however, observe that physical inactivity and increased adiposity each appears to be an independent risk factor, of about equal magnitude, that does not cancel the deleterious effect of the other risk factor.[30, 67] For type 2 diabetes, however, the data have been more consistent in showing that increased adiposity is a strong risk factor, and that physical activity or fitness does not remove the increased risk associated with increased adiposity.[63, 66]

Dose-response relationship between physical activity and health

The dose-response relationship between physical activity and health is one that has engendered a large amount of interest recently because of its importance for public health recommendations.[23, 65] Issues related to the dose-response relationship include:[26] what kinds (intensities) of activity are

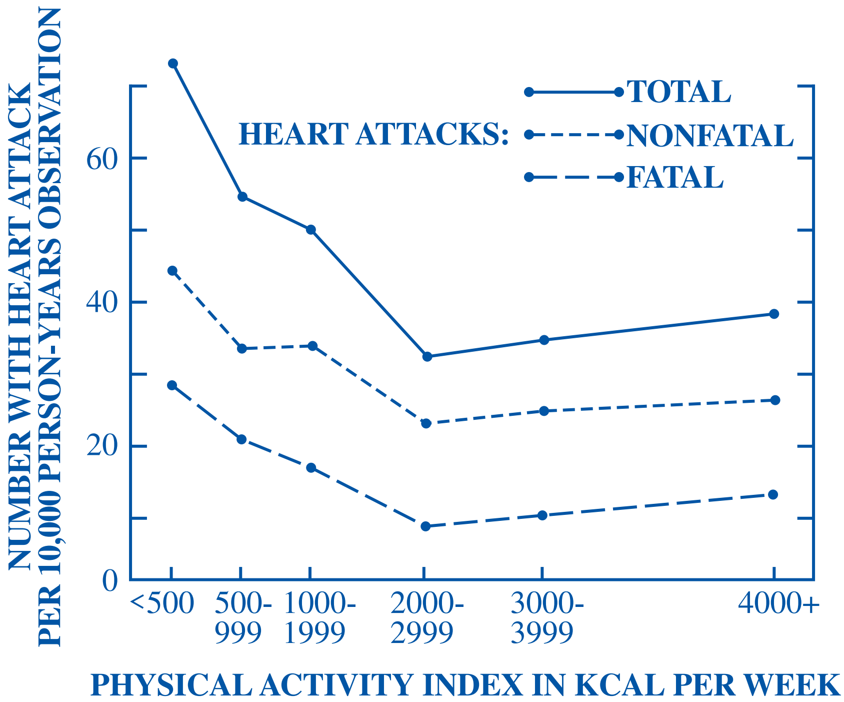

Figure 1.
Dose-response relation between physical activity and first heart attack.
From: Paffenbarger, R. S., Jr., A. L. Wing, and R. T. Hyde. Physical activity as an index of heart attack risk in college alumni. *Am J Epidemiol*. 108:161-175, 1978.

needed? How much activity (total activity, frequency, duration)? What patterns of activity? What is the shape of the dose-response curve?

Dr. Paffenbarger had already begun study of dose-response relationships in detailed fashion several decades ago. In his landmark study published in 1978,[58] he noted an inverse dose-response relationship between physical activity and first heart attack (Figure 1). This detailed analysis allowed observation of the following: (a) the lack of a "threshold" for a benefit of physical activity; (b) the steep decline in the early part of the curve, followed by less steep declines (i.e., a curvilinear shape to the dose-response curve, indicating large reductions in risk with small amounts of physical activity between 0 and <1,000 kcal/week; additional risk reductions with additional amounts of physical activity beyond 1,000 kcal/week, but at smaller magnitudes); and (c) a plateau in the curve beyond 3,000 kcal/week or so.

In a recent review of the literature for the 2008 *Physical Activity Guidelines for Americans*, there was a strong emphasis on the dose-response relations between physical activity and various health outcomes, because of their importance for public health guidelines.[65] One outcome for which there is a reasonable body of evidence to describe the dose-response curve is all-cause mortality, with the scientific committee concluding:[65] "The dose-response curve relating different amounts of physical activity to all-cause mortality rates appears curvilinear. On average across studies, compared to less than 0.5 hours per week of moderate-to-vigorous physical activity, engaging in approximately 1.5 hours per week of such activity is associated with about a 20% reduction in risk. Additional amounts of activity are associated with additional risk reductions, but at smaller magnitudes, such that an additional approximately 5.5 hours per week is required to observe a further 20% in risk (i.e., approximately 7.0 hours per week is associated with about a 40% reduction in risk, compared with less than 0.5 hour per week)." The research informing these conclusions used many of the principles from Dr. Paffenbarger's classic 1978 study.[58]

Influence on Future Contributions

It is difficult to overstate the importance of Dr. Paffenbarger's contributions not only to the development of the field of physical activity epidemiology, but also his continued influence on the discipline. His work, and that of his contemporaries (e.g.,[38, 39, 64]), resulted in the development of the methodological tools and the initial discoveries that serve as a critical part of the foundation upon which our field rests. His research accomplishments facilitated the migration of exercise physiologists toward the study of health in populations, and for those with training in epidemiology and public health, to the study of exercise and physical activity. His remarkable citation record, detailed in the conclusion below, is indicative of the level of influence he has had, and the continued high level of citation of his work is a clear indicator of the number of actively working investigators who have assimilated his body of work into their own scientific perspectives. Thus, one of Dr. Paffenbarger's key influences on the future of physical activity epidemiology is his role in helping facilitate the establishment of a large and growing cohort of investigators who study physical activity and health, and who are working to address the present day challenges to this field. These challenges include the need to add to the evidence base demonstrating the many health benefits of an active lifestyle by continuing to identify new associations between activity behaviors and health outcomes, by gathering additional information on suspected associations, and by refining our understanding of the dose-response relationship between physical activity and disease outcomes with established associations.

We face these challenges in a society that, in technological terms, has advanced rapidly in the last fifty years, and these changes have quietly reduced the level of physical exertion required each day to navigate life at home, work, school, and during leisure time, while at the same time encouraging us to spend an increasing amount of time in purely sedentary behaviors.

Dr. Paffenbarger encountered a similar type of temporal change in work activity in his study of longshoremen.[40] Occupational physical activity was once a major contributor to daily energy expenditure for those in the work force and the opportunity to contrast highly active with more sedentary occupational groups offered Dr. Paffenbarger and others a unique natural experiment with which to study the health effects of physical activity. However, during the longshoremen's study, technological advances on the docks dramatically reshaped the physical demands of their workplace. At the beginning of the study (1951-60), 40% of longshoremen engaged in heavy work that proved to be protective for coronary heart disease mortality, but this declined to 15% by 1961-70, and only 5% by 1972.[40] This led Dr. Paffenbarger to make the statement:[40]

> *If high energy output is protective, workers thus deprived of heavy work on the job may have to compensate by vigorous leisure-time activities, lest they encounter increased risk of fatal coronary heart disease.*

Participation in leisure-time activity in the United States did increase during the 1960s and '70s,[21] but since then the prevalence has remained relatively stable.[65] An important question that is now being considered is whether or not this increase has been sufficient to compensate for the loss of physical activity energy expenditure at work, school, and home.[15]

While precise data characterizing the long-term trends in the full range of physical activity behaviors in which we engage on a daily and/or weekly basis are not available, evidence is available from a variety of sources[8, 9] that supports the idea that physical activity at work and at home has declined since the middle of the last century, while the amount of time spent in purely sedentary behaviors has increased. First, in the workplace, between the middle of the last century (1950-60) and 2000, the relative change in the proportion of workers in highly active occupations decreased by 25%, while the proportion of workers in more sedentary occupations increased by 83%.[8] During this same period, the proportion of workers who walked to and from work decreased by 71%, and the use of public transportation to get to and from work declined by 69%.[8] Second, reductions in activity at home may also have been substantial. Labor-saving devices for the home were rare before World War II but since then they have proliferated rapidly, such that in 2005 about 80% of U.S. household owned a clothes washer and/or dryer; 90%, a microwave; and nearly 65%, a dishwasher.[9] While the amount of time spent on housework increased for men between 1965 and 1995, the time women spent in housework deceased about 50%—from 28 to 15 hrs/wk.[8] Similarly, the emergence of countless labor-saving lawn and garden devices (e.g., blowers, trimmers, mowers) would also appear to have contributed to reductions in both the amount of time and the level energy required to complete one of the most common types of leisure-time physical activities.[65]

Meanwhile, the amount of time we spend in sedentary behaviors (sitting) has likely increased. For example, as the proportion of households with cars increased from roughly 50% in 1950 to more than 90% today,[9] the number of miles traveled by motor vehicles each day increased by 224%.[8] The rapid proliferation of inexpensive consumer electronic devices has filled our daily home-life with an increasing number of highly seductive pursuits that makes spending time in a chair or on the couch more and more alluring. For example, as the prevalence of TV ownership increased from 10% of U.S. households in 1950 to more than 95% today, TV viewing also increased from about 4.5 to 7.0 hrs/d.[8] In 2005, about 85% of U.S. households owned VCR/DVD players, 75% owned computers, and nearly 65% had internet access.[9] We recently described the total amount of time spent in sedentary behavior in the U.S. using an objective measure in the National Health and Nutrition Examination Survey, 2003-2004.[37] Children and adults spent 54.9% of their monitored time (7.7 hours/day) in behaviors that expend very little energy. The most sedentary groups, older adolescents and adults aged 60-85 years, spent about 60% of their waking time in sedentary pursuits.

The influence of sedentary behaviors on hard disease end-points is less well-established than that of active behaviors because of our historical focus on moderate-vigorous leisure-time activity and the lack of instruments specifically designed to carefully assess the full range of sedentary behaviors. Time spent in sedentary behavior has been associated with reduced physical activity energy expenditure, sometimes called non-exercise activity thermogenesis (NEAT),[35] and is an important determinant of weight gain.[7, 35] Studies have reported significant positive correlations between TV viewing and adiposity,[3, 10, 12] weight gain,[19, 24, 60] and an adverse metabolic profile.[3, 12-14] Results from the Australian Diabetes, Obesity, and Lifestyle study provide evidence that sedentary behaviors assessed by both self-report[11] and objective measures[16] positively associate with 2-hr post-load glucose levels, independent of physical activity levels. Prospective epidemiologic studies provide evidence that sedentary behaviors are associated with increased risk of type 2 diabetes, even among relatively active adults.[18, 19] These findings are beginning to challenge the idea that moderate-to-vigorous intensity activity alone provides health benefits, and they may someday challenge our ideas about the type, intensity, frequency and duration of active behaviors that influence risk for disease.

Conclusions

It is obvious that Dr. Paffenbarger was one of the leading researchers in the area of physical activity and health. We can quantify his contributions using the Web of Science, which lists the number of times others have cited a paper and also the total number of citations. Many scientific papers are never cited at all by other researchers and of the papers that are cited at least once, the average number of citations is ~10. Any paper cited 50 times may be considered a "citation classic." The analysis for Dr. Paffenbarger lists 187 publications, which have been cited a total of >20,000 times and his work is currently receiving ~1,000 citations/year. Few individuals in our field have such high figures; indeed, some people may not have more than 1,000 citations to their work over entire careers. Further, Dr. Paffenbarger has 41 papers that have each been cited >100 times, and 5 papers that have each been cited >1,000 times, which is a truly remarkable record. The Web of Science also reports a metric called the h-index, which is an overall indicator of the influence of a scientist's work. Dr. Paffenbarger's h-index is 63. To put that in context, it is stated that an h-index of 18 is consistent with promotion to Professor at a major university; and that an h-index of 60 identifies "truly unique individuals." This latter statement certainly characterizes Dr. Paffenbarger, and our field is fortunate to have had his guidance and many contributions over the years. He will be missed.

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Dr. Ralph Seal Paffenbarger, Jr. was one of the pioneers in the field of epidemiologic research on physical activity and health: many, if not all, individuals conducting research in this area have been influenced by some aspect of his work. This paper outlines some of Dr. Paffenbarger's key contributions to the field – past, present, as well as future contributions.

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