Explaining Performance in Elite Middle-Aged Runners:
Contributions From Age and From Ongoing and Past Training Factors

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Researchers have contended that patterns of age-related decline are not necessarily due to age, but rather to disuse, or declining practice (Bortz, 1982; Ericsson, 2000; Maharam, Bauman, Kalman, Skolnik, & Perle, 1999). A regression approach was used to examine age and training variables as predictors of 10-km running performance between 40 and 59 years of age. A sample of 30 Masters runners (M age = 50.1 years, M 10-km time = 39:19) reported data for ongoing training, cumulative running in the past 5 years, and cumulative running earlier in a career. In Analysis 1, ongoing training variables explained more variance in performance than age alone, and reduced the unique variance attributable to age in a combined model. In Analysis 2, findings were replicated using past cumulative running variables and age; running in the past 5 years explained more unique variance than age alone. Discussion focuses on how findings relate to the selective maintenance account (Krampe & Ericsson, 1996), how various aspects of training help to preserve performance in aging populations, and recommendations for future research.

Keywords: aging, practice, maintenance, Masters athletes

A wealth of lifespan and gerontology research has demonstrated the deteriorative effects of aging. Patterns of age decline have been well documented for measures of speeded perceptual or cognitive motor function (Salthouse, 1992), components of memory (Henry, MacLeod, Phillips, & Crawford, 2004), reaction time (Etnier, Sibley, Pomeroy, & Kao, 2003), and nerve conduction speed (Cerella, 1990). Examinations of various physiological capacities (Wiswell et al., 2001), measures of muscular strength (Metter et al., 1999), and flexibility (Einkauf, 32001) have shown declines with age.
Gohdes, Jensen, & Jewell, 1987) all imply a downward spiral of functional ability with age. More generally, examinations of athletic performance have demonstrated inevitable and increasingly greater age-related decline as athletes advance from the age of peak function into middle- and old-aged years (e.g., Baker, Tang, & Turner, 2003; Hartley & Hartley, 1984; Slade, De los Santos-Posadas, & Cress, 2003).

Although aging effects are irrefutable, there is some question as to how much these pronounced trends reflect primary aging, and how much inactivity or “disuse” (Bortz, 1982) exacerbates these trends. Many theorists contend that trends for age-related decline are pronounced due to declining involvement (Maharam et al., 1999), or insufficient practice (Ericsson, 2000). Thus, a promising avenue of research has been to examine age-related patterns from populations of highly active and sufficiently practiced individuals. A cohort of individuals called Masters athletes (Masters) has received a great deal of attention because they continue to train systematically for, and compete in, various sport disciplines well beyond the typical age of peak performance, and often into old age. Investigations of Masters are valuable because they can inform us about age-related processes in a sample that represents the physical and functional elite of an ever-aging society, and they might be able to inform us about how individuals selectively maintain skilled motor performance as they age.

Based on work in the cognitive-motor domain, Krampe and Ericsson (1996) advanced the selective maintenance account for skilled aged performance. They posit that normal rates of age decline for performance can be substantially moderated if individuals engaged in large amounts of domain-specific “maintenance practice.” It was proposed that skilled performance could be retained at older ages as long as individuals have continuously practiced across the lifespan in a particular domain of expertise, and have engaged in specific practice activities that are most relevant for improving performance. The account proposed a preservative role for practice activities during older ages, but also preservation that was attributable to activities that had been accumulated across the lifespan. In the current study, we examine the specificity and continuity aspects of this account with respect to the running performance of elite Masters runners. To our knowledge, this framework has yet to be tested using samples of highly skilled Masters. It is possible that the preservative effects of training might differ in a physical domain such as running compared with a cognitive-motor domain. There were advantages for using running (athletics) as the research domain. Athletics has standardized metrics for performance and training that do not change across the lifespan. Moreover, through training journals, many Masters have personally archived their own records of performance and practice across long periods of time. These factors enable researchers to circumvent the difficulties associated with longitudinal research, by collecting data retrospectively and reliably reconstructing long periods of involvement for active sporting individuals (Starkes, Weir, & Young, 2003).

Various approaches have been taken to understand the effects of continuous lifespan sport involvement on the age-related processes of Masters. First, researchers have empirically described the age-related rates of decline in performance for Masters and contrasted these rates with figures believed to represent normal aging trends. For example, Baker, Horton, Pearce, and Deakin (2006) discovered that
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continuously engaged professional golfers’ performance declined at an annual rate of 0.25% from ages 51 through 60, which was far less severe than the 0.5% general rate of slowing expected for normal, less-trained populations (Bortz & Bortz, 1996). Second, researchers have contrasted longitudinal and cross-sectional athletic performance data from Masters (Starkes et al., 2003). Longitudinal data consist of within-participant data points spanning numerous years in each athlete’s career. Cross-sectional data are from archived records and are believed to represent normal rates of aging, independent of training effects. Rates of age-related decline are typically more moderate for longitudinal data, reflecting inherent cohort factors associated with participants’ continued immersion in the sport and persistent training, although researchers do not have figures to indicate how much training (Stones & Kozma, 1982). Recently, investigators have compared retrospective longitudinal and cross-sectional data trends using regression analyses for age and performance data. These analyses were guided by the proposition that quadratic betas could be used in an interpretative manner to infer the moderating role of training on rates of age decline (Starkes, Weir, Singh, Hodges, & Kerr, 1999; Weir, Kerr, Hodges, McKay, & Starkes, 2002; Young, Weir, Starkes, & Medic, 2008). For example, in a sample of Canadian Masters runners, Young and Starkes (2005) found more evidence of quadracity indicating accelerated age-related decline in cross-sectional samples than in longitudinal samples that had trained systematically for over 20 years.

In each of the aforementioned sport studies, researchers inferred a preservative or moderating role of career-span training on age decline. This inference appears to be contingent upon the validity of certain assumptions, that (a) highly active samples had indeed engaged in high volumes of practice and that (b) retrospective longitudinal samples did indeed have inherent training effects. In certain cases, continuous training was assumed by “proxy” based on the fact that athletes continued to compete across many years (Baker et al., 2006); however, researchers had no idea of how much practice had been accumulated at various points across the span. In cases where researchers collected retrospective longitudinal data (Starkes et al., 1999; Weir et al., 2002; Young & Starkes, 2005), only age and performance data were entered into regression analyses. A more reliable examination of the effects of practice on the performance of Masters would entail regression analyses, including data for individual differences in age and lifespan training data, to explain performance. To our knowledge, no research has yet conducted such analyses using a highly involved/trained sample of elite older athletes.

There is a precedent for such an approach in a study (Krampe & Ericsson, 1996) that examined how well older musicians maintained skilled performance beyond peak age. Investigators tested four groups of pianists (young amateurs and experts, plus old amateurs and experts) on a battery of skilled piano tasks. Hierarchical regression analyses were employed to account for individual differences in piano performance using three sets of predictor variables: a design factor model that included age (i.e., young/old) and skill group (i.e., expert/amateur), a model that “combined” the design factors with lifespan practice variables, and the lifespan practice variables alone. Results showed that much of the variance related to skill and age factors in the design model was equally well accounted for by differences in practice and that, when practice measures were entered into the combined model, unique effects attributable to age were significantly reduced. For the
experts, inspection of the residuals in the practice model showed that virtually all of the age-related differences in performance could be accounted for by practice. A completely different pattern emerged for amateurs (see Krampe & Ericsson, 1995), due to the fact that they had engaged in significantly less training compared with experts at each period of their careers (Krampe & Ericsson, 1996). Additional analyses for the older experts ($M$ age = 60.3 years) showed that accumulated practice during the last 10 years before the study was the only significant correlate of piano performance; neither practice until age 20 years, during a peak 20-year phase, nor current practice was highly correlated with aged performance. They concluded that the amount of training invested during later career phases, most pivotally from 50 to 60 years of age, moderated the normal age decline in experts.

Our aim was to examine the relative contributions of both training and age to the explanation of running performance for a sample of active, continuously involved Masters in the middle years of life. Data for 40 to 59 years were chosen to maximize our sample size (see Medic, Starkes, & Young, 2007, for registration figures) in an age bracket sufficiently elder to the age of peak performance so as to expect age-related decline (Ericsson, 1990). Retrospective data for ongoing training at the time of performance in the middle years of life and cumulative training at different periods earlier in a career were inserted into hierarchical regressions; thus, analyses were assumed to reflect individual differences in practice. In Analysis 1, the goal was to determine differences in predictive power between age and a model that reflected ongoing training at the time of performance. In Analysis 2, the goal was to determine differences in predictive power between age and a model that reflected past training from two different periods—cumulative running in the last 5 years up to and including middle-aged performance, and cumulative running from all time periods earlier in the career. In general, the reduction of age-related variance by practice variables would offer support for the notion of preservation and selective maintenance.

**Method**

**Participants**

Questionnaires were distributed to 226 Masters runners who were participating at either the 2004 Canadian Masters Athletics Association Championship, or the 2004 or 2005 United States Track and Field Association Masters Outdoor Track and Field Championships. Participation was voluntary and athletes were assured of confidentiality before completing a survey questionnaire. All procedures received institutional ethics approval. Of the participants who returned their questionnaires using prestamped, addressed envelopes, 43 were middle aged (i.e., 40 years of age or older) and were currently competing in the 10-km event.

**Survey Instrument**

We employed a modified version of the retrospective deliberate practice (Ericsson, Krampe, & Tesch-Römer, 1993) questionnaire that has been used previously to examine the relationship between age and sport performance. In the first sec-
tion of the questionnaire, participants entered information along a timeline, indicating each year of their life that they had trained or not trained for running, and each year in which they had experienced injuries of sufficient severity to impair their training. In the second section, they were asked to record the number of kilometers that they ran (i.e., warm-up and cool-down, speed/power, and endurance training) and how much time (in minutes) that they spent in nonrunning activities (i.e., weight training, and technique) during a typical week of training in the current year. Information was also obtained for the length of their off season (in weeks) in the current year. Next, participants recorded training amounts (kilometers and minutes) and off-season lengths (in weeks) working back retrospectively for 5-year intervals of their careers (5 years ago, 10 years ago, and so on). The use of 5-year recall intervals was a modification of Ericsson et al.’s (1993) original questionnaire, which entailed recall on a yearly basis, and also differed from other versions of the questionnaire employed with younger athletes who were asked to recall at 3-year intervals (e.g., Hodges & Starkes, 1996). Five-year intervals were chosen because they are a natural unit of recall for Masters who compete in 5-year competitive brackets; furthermore, 5-year intervals had been employed previously in retrospective questionnaires with older athletes (Young & Starkes, 2005). In the third section, participants were asked to provide their fastest personal records of performance for the 10-km event in the current year, and retrospectively at each 5-year interval in their careers. Participants completed the questionnaires off-site and were explicitly instructed to retrieve and consult their own training logs whenever possible to facilitate the entry of information. When they were recording data at each 5-year interval in the survey, participants were asked to indicate (yes/no) whether they had used a training log to enter the information for the training data, as well as whether they had used an archived log to enter their performance time.

This retrospective recall technique has been used with musicians (Ericsson et al., 1993) figure skaters (Starkes, Deakin, Allard, Hodges, & Hayes, 1996), triathletes, and swimmers (Hodges, Kerr, Starkes, Weir, & Nanamidou, 2004). Ericsson et al. (1993) demonstrated that musicians could accurately report weekly durations of stable, habitual activities such as practice, with moderately high concurrent validity values ($r = .74$) between estimates of weekly practice and values derived from diaries. While the reliability of recall for sport practice-related activities has not been the sole focus of any studies (see Côté, Ericsson, & Law, 2005), there have been some attempts to evaluate it. Ward, Hodges, Starkes, and Williams (2007) assessed the reliability of recall for time spent in soccer practice activities in a sample of young competitive players. Significant retest correlations ($r > .91$) were found for recall for the past 5 years of training, and significant correlations ranged from .68 to .62 for recall between 6 and 10 years retrospectively. Helsen, Starkes, and Hodges (1998) assessed the reliability of recall of both individual and team practice activities for 10 soccer players by administering the same questionnaire 6 months apart. The recall of the practice activities was significantly correlated ($r = .93$). Similar results were reported by Hume, Hopkins, Robinson, Robinson, and Hollings (1994) over a 10-week period for rhythmic gymnasts ($r = .84$). Other researchers have directly evaluated the long-term recall of light, moderate, and vigorous physical activities. Evidence from Blair et al. (1991); Slattery and Jacobs (1995); and Falkner, Tervisan, and McCann (1999)
suggests that vigorous activity can be adequately recalled over periods ranging from 5 to 30 years, with significant correlations between .34 and .64 for recall over 10 years, and interclass correlations in the range of .40 over 30 years. In comparison with these latter three studies, which assessed the recall of physical activity participation in nonsporting samples, it was assumed that the reliability of recall in the current study would be at least equal or higher, considering that Masters have been portrayed as committed, competitive athletes (Hodge, Allen, & Smellie, 2008) who are emotionally invested in their sport (Stevenson, 2002).

Importantly, the use of training logs by participants to enter information was expected to ensure the validity of questionnaire data. It is common practice for runners to enter details in a personal log to summarize what they did in training or competition, soon after the event has been completed. Athletes typically store these logs to look back upon them at a later time, and it is often possible to observe athletes carrying these personal archives with them to training and race venues (Landers, 2001). At the very least, they appear to be effective external memory devices for recall and, at best, archives from which athletes might extract exact values for training and performance (Starkes, Helsen, & Jack, 2001). Using a sample of triathletes, Baker, Côté, and Deakin (2005) employed archived training logs as the “gold standard” against which they validated training data that had been recalled for durations ranging from 2 to 7 years. They noted a high degree of agreement between recall estimates and values derived from logs ($r = .72$) for total number of hours of training per year.

**Selected Database**

On a within-participant basis, the database included a single case for each athlete’s performance time in the 10-km event, and the age when that performance was achieved. We used each participant’s performance at the oldest age that fell within the 40- to 59-years period of life. For the majority of participants, this represented their performance in the current year. For individuals who were older than 59 years ($n = 14$) when they completed the survey, we used the performance time at the oldest reported age before 60 years. The performance time for these individuals was not a current one but was a recollected one; on average, there were 4.4 years ($SD = 4.6$; range = 1–15) between the current age for these participants and the age of their recollected performance.

On a within-participant basis, each individual reported the amount of training that they engaged in at the time of the performance (in the 40- to 59-years period of life), but they also retrospectively recalled amounts of training at multiple 5-year intervals earlier in the lifespan. It was possible therefore for a present-day 58-year-old participant to have reported a current performance point at age 58, with corresponding training data sampled from when he or she was 58, 53, 48, 43, 38, and so on, years of age.

**Dependent and Independent Measures**

The dependent measure was the performance time that each participant recalled having achieved at the oldest age during the 40- to 59-years period (hereafter referred to as *performance*). The independent variable *age* was entered for each
participant based on the year in which the performance was achieved. The independent measure ongoing weekly training represented the sum of all kilometers that participants completed for all running activities in a typical week of training during the year of the performance. Retrospective data derived from the survey were important for calculating two independent measures for past amounts of running practice:

1. *Training (in kilometers) for all running in the past 5 years.* This value indicated the cumulative amount of running in the 5 years leading up to and including the year of performance. This value was derived from a series of calculations involving retrospective linear interpolation. Using each participant’s estimate for the length of their off season (in weeks) during the year of the performance, ongoing weekly training was converted to an ongoing annual training amount; that is, Weekly Amount × (52 minus Number of Off-Season Weeks). This ongoing annual amount was then multiplied by 5, with the following exceptions—the multiple of 5 was reduced by 1 for each year in the past 5 that the participant indicated that they had not trained.

2. *Training (in kilometers) for all running earlier in a career.* This value indicated the cumulative amount of running across a career, up until the last 5 years before the performance. For each 5-year interval of a participant’s career, the respective estimates for weekly training, length of an off season, and indications of nontraining on the timeline were used to derive totals via retrospective interpolation. All totals for the various 5-year intervals were summed to obtain career values, excepting the most recent 5 years.

**Data Analyses**

We conducted separate hierarchical regressions to address two questions: (a) whether measures for ongoing weekly practice predicted performance as strongly as age and (b) whether measures for past amounts of practice predicted performance as strongly as age. We attempted to answer the first question in Analysis 1 by successively implementing three sets of predictor variables to explain performance: (1) age alone, (2) a combined model in which age was entered simultaneously with ongoing weekly running (in kilometers), and (3) a training model comprising ongoing weekly running. In this final step, age was removed from the model.

To answer the second question in Analysis 2, three sets of predictor variables were successively regressed on performance: (1) age alone; (2) a combined model that entered age simultaneously with training over the past 5 years and training earlier in a career; and (3) a training model comprising training over the past 5 years and training earlier in a career. Age was removed in the final step of the analysis. An ancillary purpose of this analysis was to examine whether the predictive value of specific training activities was a function of the recency of accumulated practice. Although literature (Newell & Rosenbloom, 1981) suggests that the relation between practice and acquired level of performance is nonlinear and best described by a power function, support for this assumption is weaker at points beyond the initiation of training (i.e., in middle-aged periods; Krampe & Ericsson, 1996). Thus, only the linear relationships were examined in the present analyses. Alpha was set at $p < .05$ unless otherwise indicated.
Several inclusion criteria were applied to the sample. First, all participants were at least 40 years of age at the time of the study and had recalled data spanning at least 5 years of a running career (that included at least 1 year during the 40-to-59 period). Second, we included participants whose careers were relatively uninterrupted by injury and who had engaged in remarkably high levels of run-specific training throughout their careers. Specifically, there were eight participants who demonstrated substantially fewer years of uninjured training (<9 years) compared with the overall sample \((M = 24\text{ years of uninjured training}, SD = 10.4)\). Coincidentally, these same eight individuals each displayed a level of training in nonrunning activities (>321 min per week) in the year of the performance that was substantially higher than the level for the overall sample \((M = 133.2\text{ min per week}, SD = 120.3)\). These individuals were not included in the analyses. The inclusion criteria ensured that we had a sample that was sufficiently aged and uninjured, with highly specific training that could be responsible for the retention of running performance. For Analysis 2 in particular, it was also necessary to ensure that all participants contributed multiple cases for training data on a within-subject basis. There were four participants who were included in Analysis 1 but were not included in Analysis 2 because their careers were so short and they did not report training data reaching back more than 5 years. Before each of the hierarchical regression analyses, missing data were excluded on a casewise basis, and casewise diagnostics were performed to ensure a low degree of multicollinearity.

Descriptive information for the data used in Analysis 1 and Analysis 2 is presented in Table 1. In terms of the use of personal training logs, 26 out of the 30 participants in Analysis 1 used their logs to enter the data point for training and 27 participants acknowledged using their logs to enter their performance time. In Analysis 2, all 25 participants acknowledged using a log to enter information for training and the performance time. Table 2 indicates the extent to which participants in Analysis 2 acknowledged using logs to enter information in the survey. Collapsed across all participants, 115 out of the 164 points (70.1%) employed in the interpolative and multiplicative procedures for the calculation of cumulative training measures had been entered using a log.

It is important to point out the elite performance level of the Masters in the present investigation. The mean performance times for each of the constituent samples were similar and all were below 39 min and 20 s for a 10-km race. To put this in context, the mean performance time for male athletes in Analysis 1 would have placed them 25th in the world 10-km track championship, based on a 5-year rolling average of results (World Masters Athletics, 2006). Based on age-graded scoring tables (World Association of Veteran Athletes, 1994), our samples proved to be comprised of regional-level and national-level male Masters, and national- or international-level status females.
<table>
<thead>
<tr>
<th></th>
<th>Analysis 1</th>
<th>Analysis 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>30 (male = 26, female = 4)</td>
<td>25 (male = 23, female = 2)</td>
</tr>
<tr>
<td>Mean age of performance</td>
<td>50.1 years ( (SD = 5.6) )</td>
<td>49.7 years ( (SD = 4.9) )</td>
</tr>
<tr>
<td>Mean 10-km performance time</td>
<td>39 min 19 s ( (SD = 208 \text{ s}) ) (Range = 32 min 56 s to 46 min 13 s)</td>
<td>39 min 17 s ( (SD = 223 \text{ s}) ) (Range = 33 min 44 s to 46 min 13 s)</td>
</tr>
<tr>
<td>Mean ongoing weekly running</td>
<td>62.05 km ( (SD = 23.8) )</td>
<td>NA</td>
</tr>
<tr>
<td>Mean training in past 5 years</td>
<td>NA</td>
<td>15,610 km ( (SD = 6,736) )</td>
</tr>
<tr>
<td>Mean training earlier in a career</td>
<td>NA</td>
<td>77,566 km ( (SD = 53,659) )</td>
</tr>
</tbody>
</table>

*Note.* NA = not applicable.
**Results**

**Analysis 1: Age and Ongoing Training at the Time of Performance**

Bivariate correlations indicated that age ($r = .60$) and ongoing weekly running kilometers ($r = -.68$) were strongly associated with performance in the predicted directions; there was also a significant correlation between age and ongoing weekly running km ($r = -.52$; all $p$s < .01). The results of the hierarchical regression analysis are displayed in Table 3. The amount of variance accounted for by age alone ($R^2 = .36$) was significant, $F(1, 28) = 16.06$, $p < .001$. In the combined model, the associated incremental $R^2$ allowed an evaluation of whether the quantity of Masters athletes’ training at the time of their performance could account for individual differences in performance, even after controlling for the unique variance attributable to age. Reliably more variance was accounted for, $R^2_{\text{change}} = .18$, $F_{\text{change}}(1, 27) = 5.30$, $p < .01$. The combined model accounted for $R^2 = .54$ in running performance, $F(2, 27) = 16.40$, $p < .001$. When age was removed, the practice model accounted for reliable variance in performance, $F(1, 28) = 24.34$, $p < .001$, and there was very little loss in predictive power when individual differences in performance were accounted for by the training variable alone, $R^2_{\text{change}} = -.09$, $F_{\text{change}}(1, 27) = 4.99$, $p < .05$. When $R^2$ values for age alone (.36) and the training model (.45) were compared, individual differences in performance were better accounted for by differences in ongoing weekly training.

With respect to the combined model, inspection of the partial $R^2$s provided information about the degree to which variance associated with age was captured by the added training variable. First, the unique variance related to age was clearly reduced by the presence of the training variable (i.e., from .36 in the age-alone model to .15 in the combined model). Second, the ongoing weekly training variable explained substantially more unique variance ($R^2 = .28$) in running perfor-

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**Table 2 Data Indicating the Extent of Log Use to Enter Questionnaire Information in Analysis 2**

<table>
<thead>
<tr>
<th>Total number of data points entered on a within-subject basis</th>
<th>Mean number of data points entered using a log</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three ($n = 2$)</td>
<td>2.5</td>
</tr>
<tr>
<td>Four ($n = 3$)</td>
<td>3.3</td>
</tr>
<tr>
<td>Five ($n = 3$)</td>
<td>4.0</td>
</tr>
<tr>
<td>Six ($n = 2$)</td>
<td>2.5</td>
</tr>
<tr>
<td>Seven ($n = 6$)</td>
<td>4.5</td>
</tr>
<tr>
<td>Eight ($n = 5$)</td>
<td>6.4</td>
</tr>
<tr>
<td>Nine ($n = 3$)</td>
<td>6.3</td>
</tr>
<tr>
<td>Ten ($n = 1$)</td>
<td>5</td>
</tr>
</tbody>
</table>

*Note.* Numbers in parentheses represent the number of participants in that category.
Performance compared with age \((R^2 = .15)\). Furthermore, runners who were completing more kilometers per week had faster 10-km race times during this 40- to 59-year-old period \((\beta = -.50)\). (When the same analyses were performed for only the 26 participants who used a log to enter data, results were almost identical, resulting in the same interpretation.)

**Analysis 2: Age and Accumulated Training Until the Time of Performance**

Bivariate correlations indicated that age \((r = .61)\), training in the past 5 years \((r = -.73)\), and training earlier in a career \((r = -.47)\) were each significantly associated with performance in the predicted directions \((ps < .01)\); there were also significant correlations between age and training in the past 5 years \((r = -.44)\), as well as between training in the past 5 years and earlier in a career \((r = .46; ps < .05)\).

The results of the hierarchical regression analysis are displayed in Table 4. The amount of variance accounted for by age alone \((R^2 = .35)\) was significant, \(F(1, 23) = 13.93, p < .01\). When the two accumulated training variables were added into the combined model, reliably more variance \((R^2_{\text{change}} = .27)\) was accounted for, \(F_{\text{change}}(2, 21) = 9.37, p < .01\). The combined model accounted for \(R^2 = .62\) in performance, \(F(3, 21) = 14.28, p < .001\). When age was removed, the training model explained reliable variance in performance, \(F(2, 22) = 14.30, p < .001\), and there was little loss in predictive power, \(R^2_{\text{change}} = -.10, F_{\text{change}}(1, 21) = 6.75, p < .05\). When \(R^2\) values for age alone (.35) and the training model (.53) were compared, performance variance was better explained by differences in past amounts of run training than by one’s age.

In terms of the combined model, the partial \(R^2\)s showed that the unique variance attributable to age alone was reduced (i.e., from .35 in the age-alone model
to .24 in the combined model) in the presence of past run training variables. Moreover, the unique variance afforded by training in the past 5 years ($R^2 = .32$) was greater than the unique variance explained by age ($R^2 = .24$). With respect to the two past training variables, the $\beta$-coefficient ($-.65$, $p < .01$) indicated that training in the past 5 years was associated with faster performances, and the $\beta$-weight for cumulative training earlier in a career was nonsignificant ($p = .29$).

### Table 4  Hierarchical Regression Analyses Implementing Three Different Sets of Predictor Variables Including Past Training

<table>
<thead>
<tr>
<th>Predictor variables</th>
<th>Partial $R^2$ values</th>
<th>$R^2$ values for a set of predictors</th>
<th>Standardized beta weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1: Age</td>
<td>—</td>
<td>.35**</td>
<td>.61**</td>
</tr>
<tr>
<td>Incremental $R^2$ for training variables</td>
<td>—</td>
<td>.27**</td>
<td>—</td>
</tr>
<tr>
<td>Set 2: Combined Model</td>
<td>—</td>
<td>.62**</td>
<td>—</td>
</tr>
<tr>
<td>Age</td>
<td>.24</td>
<td>.36*</td>
<td>—</td>
</tr>
<tr>
<td>Training in past 5 years</td>
<td>.32</td>
<td>—</td>
<td>-.49**</td>
</tr>
<tr>
<td>Training earlier in career</td>
<td>.07</td>
<td>—</td>
<td>-.18</td>
</tr>
<tr>
<td>$R^2$ removed with age</td>
<td>—</td>
<td>.10*</td>
<td>—</td>
</tr>
<tr>
<td>Set 3: Training Model</td>
<td>—</td>
<td>.52**</td>
<td>—</td>
</tr>
<tr>
<td>Training in past 5 years</td>
<td>.43</td>
<td>—</td>
<td>-.65**</td>
</tr>
<tr>
<td>Training earlier in career</td>
<td>.05</td>
<td>—</td>
<td>-.17</td>
</tr>
</tbody>
</table>

*Note. Values are for $R^2$s for variables and their combinations in the three sets of predictors. Asterisks with $R^2$ values for sets of predictors denote significance for that complete model.

*p < .05, **p < .01.

### Discussion

We examined the relative contributions of age and training toward explaining competitive running performance in the middle years of life. Whereas previously researchers have relied on inference to show how training moderated age-related decline, we actually inserted practice variables into hierarchical regressions so that values for explained variance could be contrasted with similar values attributed to the effects of age alone. We hypothesized that greater variance explained by a practice model, in contrast to a model based on age alone, would provide evidence for selective maintenance. We also hypothesized that the additional overall variance explained by practice variables in the combined model, comparatively larger residuals for training compared with age, and a reduction of the age-related residual in the combined model would offer support for the notion of preservation.

In Analysis 1, results showed that an ongoing training variable (i.e., amounts of weekly training during the year in which performance was achieved) accounted, on its own, for more variability in running performance than age alone. Moreover,
when the amount of ongoing weekly practice was considered in combination with age, additional overall variance was explained, and the unique variance associated with age was significantly reduced. The results from Analysis 2 demonstrated the important role of practice in explaining elite running performance into the middle years of life. A training model comprised of running training from past periods in a career accounted for significantly more performance variance than age alone. When the amount of past cumulative running was considered in concert with age, more overall variance was explained, and the unique variance associated with age was reduced. The contribution of past training variables replicated the findings for ongoing training variables in Analysis 1, specifically, that the predictive power of a model based on past cumulative running training was stronger than one based solely on age. However, the partial variances for age and training in the past 5 years were closer in value (.08) in Analysis 2 than the difference in partial variances attributed to age and ongoing weekly training (.13) in Analysis 1.

The findings demonstrate the effects of aging on running performance; running performance slows with advancing age. The current data, however, shows that intensive specific training evidenced by this remarkable cohort of athletes serves to modify the unique variance attributable to effects of “primary aging” processes (Salthouse, 1991, p. 20). Whereas aging is inevitable, training is, to a certain degree, under the control of the individual if they are motivated; have access to adequate resources such as equipment, coaching, and facilities; are able to remain free of injury; and are not compromised by the effects of “secondary processes of aging” (Salthouse, 1991, p. 20). For example, one secondary aging effect might include the self-damage that arises from prolonged training over many years, which in turn may hinder one’s opportunity to train. Within this context, the current results suggested that the primary effects of aging became less pronounced when the effects associated with intensive and highly specific practice (both ongoing, and accumulations in the most recent past) were considered in the explanation of performance. It is interesting that the moderating effect of training was evidenced for kilometers run, which is a composite variable that comprises all running activities. If one were to collect information exclusively relating to the most intense training, such as average mile times, amount of interval training, and fartlek, this possibly would further increase the predictive power of the training data (Ericsson, 2000).

According to the selective maintenance account (Krampe & Ericsson, 1996), skilled performance is retained into older ages when individuals engage in great amounts of practice early in a career, and then maintain the specificity, intensity, and volume of their practice as they age. Although the notion that intense and voluminous training is associated with elite performance in middle age was supported in the current study, a fuller confirmation of selective maintenance is predicated on the demonstration of significant contributions from cumulative training variables at even earlier periods of the lifespan (i.e., in the more distant past). Results for Analysis 2 showed that middle-aged running performance was predominantly related to training in the past 5 years, up to and including the performance, as distant totals from earlier in a career failed to account for unique variance. Krampe and Ericsson (1996) reported similar findings when they examined the contribution of practice to skilled musical performance in 60-year-olds. For these musicians, there was a significant contribution from the most recent 10 years
of practice, yet neither cumulative practice during the first 20 years of life nor cumulative practice during 20 years of peak practice reached significance. Therefore, there continues to be a need to statistically demonstrate how early-life training/practice is associated with skilled performance in later decades.

The accumulations of training across 5 years, and across longer spans as well, depend very much on the continuity of an athlete’s investment in addition to the ongoing training value. It is important to understand what dictates continuity in training. There were three aspects of continuity inherent in our cumulative independent measures that would appear important for preserving aged sport performance: many years of uninterrupted practice, shorter off-season periods, and higher weekly amounts of practice. Preliminary evidence, which describes the remarkable motivational profiles of older competitive athletes (Hodge et al., 2008), suggests that Masters athletes are self-determined, goal-oriented, and committed to sport. For that reason, it is possible to understand how such a profile propels these individuals to train continuously, more frequently, and more intensively. On the other hand, it is also not possible to discount an interpretation that individuals who are able to avoid injury or sport-specific wear-related degradations in the body are able to engage in such a comprehensive training schedule and thus are better able to retain skilled performance at a higher level.

While motivation and effort are arguably in the control of the individual, wear-related degradations likely constitute an irreversible constraint over which the individual has substantially less control. Although participants in the current study were asked in the survey to recollect years in which they experienced significant injuries that impaired their training, how to include injured years in the interpolation of cumulative training data became a challenge. We did not include injuries in the interpolation because, if a participant reported a serious injury in a particular year, we did not know whether this should discount that individual’s training for the entire year or whether the injury may have simply compromised the training data as athletes still find ways to train while injured. In the future, researchers could incorporate sensitive measures for assessing injury into the retrospective methodology, thereby making it possible to determine whether there is a selection effect in elite Masters runners. This selection effect might reflect a wear constraint on "maintenance training," which may be in part due to innate/inherent factors that buffer them against secondary aging decrements, or exogenous aging effects (Salthouse, 1991). Moreover, better consideration of injury nuances and less specific training activities (e.g., cross-training) might afford a study of compensatory mechanisms (Baltes, 1987; Salthouse, 1992) that elite athletes use to circumvent wear constraints related to training as they age.

In sum, middle-aged athletic individuals who retain a high level of performance do so likely because they have maintained years of uninterrupted practice, consistently have shorter off-season periods, exhibit higher weekly amounts of practice, and avoid injury. Future research will be essential to distinguish the importance of each of these aspects over time. To this end, the retrospective recall methodology should be expanded to include measures for more points across the lifespan, by collecting data for shorter intervals instead of the present 5-year intervals. Although the method of using archived logs to reconstruct practice histories is a methodological advance, investigators should consider independently validating a random selection of the archived log information with the information that
is actually entered in the questionnaire. In the future, researchers might also continue to establish the reliability of retrospective longitudinal questionnaires using techniques such as a standardized interview protocol (Côté et al., 2005; MacDonald et al., 2006). To ensure that the data has the highest degree of reliability, participants’ performance times should be corroborated with archived race results, and there should be efforts to perform test–retest analyses on retrospective data. The present findings should be understood with respect to the limitations of the current retrospective methodology.

Building upon the current study, future researchers should employ a similar approach in an attempt to replicate the present findings for other measurable sports, particularly those that have intrinsic metrics for training and performance such as swimming, cycling, and triathlon. It might also be informative to examine how the relative contributions of age and training factors change at different epochs across the lifespan, for example, at older stages from 60 to 79 years of age. If sufficiently large sample sizes can be ensured, future research should consider regressing training variables from different life phases (e.g., training before age 30, training in the 30s, training in the 40s) on performance. This approach would allow an examination of interactive effects between age and training that were not captured in the present analyses and might indicate how the unique variance afforded to training may change in even older sporting cohorts. In this manner, researchers might gain insight into the critical phases of training for maintaining elite sport performance. It will also be important for investigators to consider how different activities within the microstructure of practice, of varying intensities, each serve to moderate the effects of primary aging. How aging athletes deliberately change their training microstructure at various stages across the lifespan to maintain or acquire physiological/cognitive adaptations is a ripe area for examination (Ericsson, 2007). Finally, it will be important to understand what motivates these individuals to train continuously. Investigators should respond to the call for more research that describes the unique psychological and social-psychological profile that enables these individuals to stay continuously and intensively involved in their sport (Feltovich, Prietula, & Ericsson, 2006; Roper, Molnar, & Wrisberg, 2003; Starkes et al., 1999).

In sum, the present research informs us about how aging expert or elite athletes maintain their performance. They acquire their performance capabilities by training intently and without interruption for many years, and the past 5 years appeared in the current study to be most important for bolstering running performance in the middle years of life. Undoubtedly, there is much “learning” that occurs over these years—athletes learn cognitive strategies during races such as pacing, and they learn personal meta-cognitive strategies to emphasize various activities within their practice microstructure to bring about the greatest physiological adaptations. The mechanics of such learning are obscured by the macro-analytic nature of the present investigation; future research might uncover the specifics of these aspects of skill acquisition. Alternatively, perhaps the trends for continuous lifespan training demonstrated by elite Masters is, in part, evidence of “learning.” They have learned that, to selectively maintain their skills and physiological adaptations in their sport, they must train systematically and continually. The challenge for these individuals is how to continually navigate the effort and motivational constraints to train in order to maintain their high level of performance.
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