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The Relationship Between Deliberate Practice and Performance in Sports: A Meta-Analysis

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Abstract
Why are some people more skilled in complex domains than other people? According to one prominent view, individual differences in performance largely reflect individual differences in accumulated amount of *deliberate practice*. Here, we investigated the relationship between deliberate practice and performance in sports. Overall, deliberate practice accounted for 18% of the variance in sports performance. However, the contribution differed depending on skill level. Most important, deliberate practice accounted for only 1% of the variance in performance among elite-level performers. This finding is inconsistent with the claim that deliberate practice accounts for performance differences even among elite performers. Another major finding was that athletes who reached a high level of skill did not begin their sport earlier in childhood than lower skill athletes. This finding challenges the notion that higher skill performers tend to start in a sport at a younger age than lower skill performers. We conclude that to understand the underpinnings of expertise, researchers must investigate contributions of a broad range of factors, taking into account findings from diverse subdisciplines of psychology (e.g., cognitive psychology, personality psychology) and interdisciplinary areas of research (e.g., sports science).

Keywords
deliberate practice, talent identification, sports, skill acquisition, expertise

Who becomes a success in music, sports, games, business, and other domains? This is a question that parents, teachers, coaches, talent scouts, and search committees all seek to answer—and one that psychologists have debated for as long as psychology has been a field. Galton (1869) argued that eminence in science, music, art, and other fields reflects a "natural ability." Thorndike (1912) countered that "we stay far below our own possibilities in almost everything that we do . . . not because proper practice would not improve us further, but because we do not take the training or because we take it with too little zeal" (p. 108). Watson (1930), in turn, famously guaranteed that he could take any infant at random and "train him to become any type of specialist [he] might select . . . regardless of his talents" (p. 104).

More recently, scientists interested in expertise have focused on identifying sources of individual differences in performance using psychometric, experimental, behavioral, genetic, and other research approaches. Here, using meta-analysis, we investigate how various task, participant, and methodological factors affect the relationship between deliberate practice and performance in a domain that has been of particular interest to expertise researchers—sports.

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The Deliberate Practice View

It is undeniable that some people are much more highly skilled than other people in complex domains. Nowhere is this more evident than in sports. Consider that the winning times for the 2014 New York City Marathon—just under 2 hr, 11 min for the men and just over 2 hr, 25 min for the women—were more than 2 *hours* better than the average time of all contestants (see http://www.tcsnyc-marathon.org/). Or consider that although many golfers struggle to break 100 for 18 holes, the best professional golfers average in the high 60s, playing the most difficult golf courses in the world (see http://www.pgatour.com/stats/stat.120.html).

What explains this striking variability? Over 20 years ago, in a highly influential article, Ericsson, Krampe, and Tesch-Römer (1993) proposed that individual differences in performance largely reflect accumulated amount of *deliberate practice*, which they operationally defined as engaging in activities created specifically to improve performance in a domain. In two studies, Ericsson et al. recruited musicians from different levels of accomplishment and asked them to retrospectively estimate the amounts of time per week they had engaged in deliberate practice. Group averages were highest for the most accomplished musicians. For example, on average, the "best" violinists had accumulated over 10,000 hr of deliberate practice, compared with less than 8,000 hr for the "good" violinists and not even 5,000 hr for the least accomplished "teachers." Ericsson et al. concluded that "individual differences in ultimate performance can *largely be accounted for* by differential amounts of past and current levels of practice" (p. 392, emphasis added).

The deliberate practice view is a popular account of expertise. Indeed, Ericsson et al. (1993) has been cited over 5,000 times (source: Google Scholar). Nevertheless, research indicates that deliberate practice does not largely account for individual differences in performance. Gobet and Campitelli (2007) found a large amount of variability in the total amount of deliberate practice it took chess players to first reach "master" status—from 3,016 hr to 23,608 hr. Subsequently, Hambrick et al. (2014) reanalyzed results of previous studies and found that accumulated amount of deliberate practice accounted for only about one third of the reliable variance in performance in chess and music, leaving the rest explainable by other factors.

In a meta-analysis of 157 effect sizes and a total sample size of over 11,000, we (Macnamara, Hambrick, & Oswald, 2014) found that amount of deliberate practice accounted for well less than half of the variance in performance in each of the major domains in which deliberate practice has been studied: games (26%), music (21%), sports (18%), education (4%), and professions (<1%). Some of the unexplained variance is presumably because of measurement error (i.e., the unreliability of the measures of deliberate practice and performance). However, across a wide range of reliability assumptions, the percentage of variance explained by deliberate practice was considerably smaller than the percentage unexplained. Thus, deliberate practice appears to be an important piece of the expertise puzzle but not the only piece and not necessarily the largest piece.

Present Study

In our previous meta-analysis (Macnamara et al., 2014), we focused on the relationship between deliberate practice and performance at a broad level—that is, across all domains in which this relationship has been studied. Here, focusing on a single domain, our goal is to deepen understanding of the relationship between deliberate practice and performance by testing for effects of moderator variables that cannot easily be tested across domains. Our major question in the current meta-analysis is whether the relationship between deliberate practice and performance varies as a function of different factors reflecting characteristics of individuals and of tasks.

We chose to focus on sports for four reasons. First, a rich literature in sports science identifies variables that are interesting to consider as moderators of the relationship between deliberate practice and performance (e.g., open vs. closed skill, individual vs. team). Second, by virtue of the structure and organization of sports, more information is available about the characteristics of athletes (e.g., delineated skill levels, youth vs. adult) than is available for performers in many other domains (e.g., business, science, music). This makes it possible to examine these characteristics, along with task variables, as moderators of the relationship between deliberate practice and performance. Third, unlike in some domains (e.g., the arts), there are objective measures of performance in most sports. This makes sports ideal for research on expertise, because subjective criteria for judging expertise sometimes correlate weakly with actual performance (Ericsson & Smith, 1991). Finally, sports have been used more than any other domain to study the relationship between deliberate practice and performance. This makes it possible to evaluate moderator effects with a higher level of statistical power and precision than in other domains. For all of these reasons, we view sports as an ideal test bed for an in-depth meta-analysis of the relationship between deliberate practice and performance.

We considered three types of moderator variables—those pertaining to demands of the task, characteristics of participants, and research methodology. We included some of the moderator variables in our meta-analysis for purely descriptive reasons and others to test specific theoretical predictions.

Task Demands

Both across and within domains, the extent to which a particular factor (e.g., deliberate practice) explains variance in performance may depend on task demands. We tested for effects of four moderator variables pertaining to the demands of the task that are relevant to sports. To examine the effects of whether the task involves coordination of performance with others, we included the variable *individual versus team sport*. To examine the effects of the degree to which the performer can control when to execute an action, we included the variable *externally paced* (e.g., volleyball) *versus internally paced* (e.g., darts) *sport* (Galligan et al., 2000). To examine the effects of whether a sport uses a ball or projectile, we included the variable *ball versus non-ball sport*. Finally, to examine the effects of whether the environment is changing and relatively unpredictable or static and relatively predictable during decision-making and performance execution, we included the variable *open-skill* (e.g., field hockey) *versus closed-skill* (e.g., bowling) *sport* (Knapp, 1967).

We made no prediction about how the strength of the relationship between deliberate practice and performance would differ between team sports and individual sports, between externally paced sports versus internally paced sports, or between ball sports and non-ball sports. We did, however, predict that the relationship would be stronger (more positive) for closed skill sports than for open skill sports, based on the well-established finding that effects of training on performance tend to be stronger when the task environment is more predictable than when it is less predictable (e.g., Ackerman, Kanfer, & Goff, 1995; Schneider & Fisk, 1982).

Participant Characteristics

There were two moderator variables pertaining to participant characteristics. *Youth versus adult* refers to whether the sample of athletes was recruited from a youth league or training group or from an adult sport group. Two studies (four effect sizes) combined youth and adult athletes, and one study did not report enough information for us to classify the athletes as youths or adults. We excluded the effect sizes from these studies when analyzing this moderator. *Skill level* refers to the accomplishment of adult athletes. (We only included adult athletes when analyzing this moderator because the criteria for determining skill level are often different for youth athletes and adult athletes.) There were three levels of this variable, representing three types of samples: *subelite* samples, consisting of athletes who compete at the state/provincial level or a lower level (i.e., club level, local level, and state/provincial level); *elite* samples, consisting of athletes who compete at the national level or a higher level (i.e., national level, international level, Olympic/world champion level); and *mixed* samples, consisting of both elite and subelite athletes. We chose these classifications so that they would not be overly restrictive in terms of the range of performance, making it possible to detect correlations between deliberate practice and performance if such correlations exist. That is, there was a relatively wide range of performance within both the subelite and elite classifications, as the subelite athletes ranged from recreational athletes to athletes competing at the state level, and the elite athletes ranged from athletes competing at the national level to Olympic gold medalists.

We made no prediction about how the strength of the relationship between deliberate practice and performance would differ between youth samples and adult samples. With respect to skill level, we were interested in whether the effect of deliberate practice on performance was as strong among elite athletes as among subelite athletes. According to the deliberate practice view, deliberate practice can account for performance differences even among elite performers. That is, Ericsson et al. (1993) stated that "[i]ndividual differences, *even among elite performers*, are closely related to assessed amounts of deliberate practice" (p. 363, emphasis added). Thus, we asked whether, and to what extent, deliberate practice would contribute to individual differences in performance among elite athletes. The finding of a statistically significant and sizeable relationship between deliberate practice and performance in elite athletes would support this claim of the deliberate practice view, whereas the finding of a nonsignificant relationship would be inconsistent with this claim.

Research Methodology

Finally, there were two moderators pertaining to research methodologies. *Method used to measure deliberate practice* refers to whether a questionnaire or interview was used to obtain estimates of deliberate practice from participants. *Method used to measure performance* refers to whether the measure of performance was a standardized objective measure (e.g., race time), a laboratory measure (e.g., score on a laboratory test of some athletic skill), group membership (e.g., international-level vs. recreational-level athletes), or expert rating of performance (e.g., coach rating).

Method

We designed the meta-analysis and reported the results in accordance with the Preferred Reporting Items for

Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009). See Figure 1 for a flowchart depicting the major steps of the meta-analysis.

Inclusion criteria, literature search, and coding

The criteria for including a study in the meta-analysis were as follows:

1. A measure of accumulated amount (e.g., number of hours) of one or more activities interpretable as reflecting deliberate practice (henceforth, *deliberate practice*) was collected.
2. A measure of performance reflecting level of skill in a sport was collected.
3. An effect size reflecting the relationship between accumulated amount of deliberate practice and sports performance was reported, or information needed to compute this effect size was reported or was obtained from the author(s) of the study.
4. The methods and results were in English.
5. The participants were human.

Ericsson et al. (1993) defined deliberate practice as "activities that have been specially designed to improve the current level of performance" (p. 368), and Keith and Ericsson (2007) clarified that deliberate practice activities "can be designed by external agents, such as teachers or trainers, or by the performers themselves" (p. 136). As in our previous meta-analysis (Macnamara et al., 2014), we defined deliberate practice as engagement in an activity created specifically to improve performance in a domain and allowed that the activity could be designed by external agents or by the performers themselves (see https://osf.io/rhfsk for a complete list of the studies included in Macnamara et al., 2014).

Among the studies that we included in the present meta-analysis, examples of measures that have been interpreted as reflecting deliberate practice include accumulated amount of practice alone plus practice with a partner in darts (Duffy, Baluch, & Ericsson, 2004); practice alone and practice with a team in bowling (Harris, 2008); practice aimed at improving technique in ballet (Hutchinson, Sachs-Ericsson, & Ericsson, 2013); sports-specific practice in triathletes (running, swimming, and cycling) and swimmers (Hodges, Kerr, Starkes, Weir, & Nananidou, 2004); and practice activities such as receiving coaching, technical practice, and video game analysis in soccer and field hockey (Helsen, Starkes, & Hodges, 1998). All of the studies included in the meta-analysis explicitly referred to the concept of deliberate practice.

We included all of the sports studies from Macnamara et al. (2014) in this meta-analysis; we found these studies through systematic literature searches (through March 24th, 2014) for relevant published and unpublished articles and from e-mail requests to authors of articles on deliberate practice. We also searched for relevant published and unpublished articles that became available between March 24th, 2014, and October 13th, 2014. These searches yielded 9,509 relevant articles (9,331 potentially relevant articles from the Macnamara et al., 2014, search and 178 from the search through October 13th, 2014). After examining these articles and discarding irrelevant ones, we identified 34 studies that met all the inclusion criteria.[1]

We coded each study and the measures collected in it for reference information, methodological characteristics, and results (the data file is openly available at osf.io/r5qjw and http://pps.sagepub.com/content/by/supplemental-data). Across studies, there were 52 independent samples, with 63 effect sizes and a total sample size of 2,765 participants. Of the 63 effect sizes, 38 were from published articles or chapters ($N = 2{,}066$), and 25 were from unpublished manuscripts, theses, dissertations, and datasets ($N = 699$). See Table 1 for additional characteristics of the meta-analysis.

Effect sizes and moderator variables

The meta-analysis used the correlation between accumulated amount of deliberate practice and sports performance as the measure of effect size. The majority of the effect sizes were correlations that were included in the study reports.[2] For studies in which the authors only reported group-level comparisons (e.g., international-level athletes vs. recreational-level athletes), we converted standardized mean differences (Cohen's *d*s) to biserial correlations (Becker, 1986; Hunter & Schmidt, 1990).

Individual versus team sport, ball versus non-ball sport, externally paced versus internally paced, youth versus adult sample, skill level of sample, method used to measure deliberate practice, and method used to measure performance were straightforward to classify based on information reported in the articles we collected; thus, we classified the effect sizes for these moderators ourselves. Open skill versus closed skill sport is a more subjective variable, and thus we had coaches ($N = 21$) of various sports at the first author's institution (Case Western Reserve University) classify the sports for this moderator variable. We instructed the coaches to classify a sport as an open skill sport if the environment changes continuously and is unpredictable, and to classify a sport as a closed skill sport if the environment is static and predictable. Interrater reliability was high (observed agreement = .93, Fleiss $\kappa = .86$).

There were only two effect sizes for the *laboratory measure* level of the *method used to assess performance* moderator variable; we excluded these two effect sizes when analyzing this moderator variable, because as a

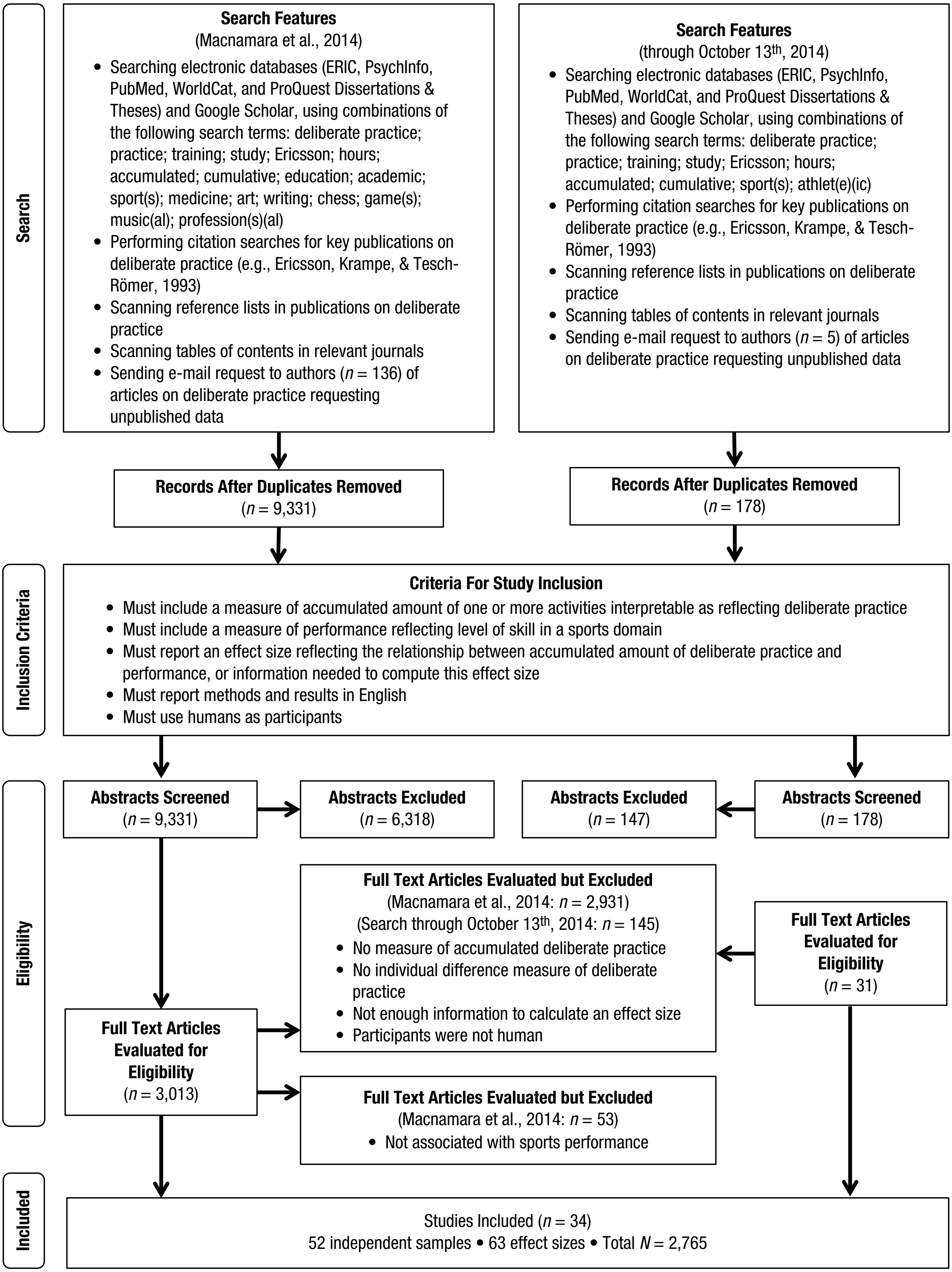

Fig. 1. Flow diagram of the literature search and study coding.

Table 1. Descriptive Characteristics of the Meta-Analysis

Study characteristic	No. of effect sizes	No. of participants
Task demands		
Team vs. individual		
Team sport	40	1,783
Individual sport	23	982
Externally paced vs. internally paced[a]		
Externally paced	43	2,079
Internally paced	5	160
Ball sport vs. Non-ball sport		
Ball sport	45	1,943
Non-ball sport	18	822
Open vs. closed		
Open skill	41	1,836
Closed skill	22	929
Participant characteristics		
Age[b]		
Youth	30	1,339
Adult	28	1,162
Skill level[c]		
Elite	6	228
Mixed	13	648
Sub-elite	9	285
Research methodology		
Method used to measure deliberate practice		
Interview	13	440
Questionnaire	50	2,325
Method used to measure performance[d]		
Standardized objective measure	15	476
Laboratory task	2	32
Group membership	32	2,041
Expert rating	14	248
Total	63	2,765

[a]For this characteristic, the number of effect sizes does not sum to 63 and the number of participants does not sum to 2,765 because sports that are self-paced but highly influenced by opponents' pace were not included in this classification.
[b]For this characteristic, the number of effect sizes does not sum to 63 and the number of participants does not sum to 2,765 because studies that mixed youth and adult athletes or did not provide enough information to confirm age status were not included in this classification.
[c]For this characteristic, the number of effect sizes does not sum to 63 and the number of participants does not sum to 2,765 because samples of youth athletes were not included in this classification. Additionally, one study did not provide enough information to classify skill level.
[d]For this characteristic, the number of participants does not sum to 2,765 because one sample contributed to multiple types of effects.

rule of thumb, at least five cases are needed per subgroup to perform a moderator analysis (The Campbell Collaboration, 2012).

Meta-analytic procedure

The meta-analysis involved four steps. The first step was to obtain correlations between time spent in one or more activities interpretable as deliberate practice and sports performance, along with sampling error variances. The second step was to search for outliers, which we defined as correlations whose residuals had z scores of 3 or greater. None of the correlations met this criterion. The third step was to estimate overall effects and heterogeneity among the correlations using random-effects meta-analysis modeling and then test whether some of the heterogeneity was predictable from moderator variables using mixed-effects meta-analysis modeling. The final step was to perform publication-bias analyses. We used the Comprehensive Meta Analysis (Version 2; Biostat, Englewood, NJ) software package to conduct the meta-analyses and publication-bias analyses. (See also Methodological Details and Screen Shots of Results, Figs. S1–S14, in the Supplemental Method and Results in the Supplemental Material available online.)

Results

The participants in the studies reflected a wide range of accumulated deliberate practice. For example, across the 28 studies that reported group-level descriptive statistics, the weighted mean hours of deliberate practice was 3,949 hr (SD = 2,942 hr), and the average hours of deliberate practice for the subgroups ranged from 4 hr for lower skill athletes to 12,839 hr for higher skill athletes. The participants in the studies also reflected a wide range of accomplishment, from recreational athletes to repeat Olympic gold medalists.

Figure 2 shows that nearly all correlations between deliberate practice and performance were positive: High levels of deliberate practice were associated with high levels of performance. The meta-analytic average correlation between deliberate practice and sports performance was .43, 95% confidence interval (CI) [.35, .50], which indicates that deliberate practice explained 18% of the variance in performance, 95% CI [12%, 25%], leaving 82% of the variance unexplained (see Fig. 3, upper panel). However, as indicated by the I^2 statistic, which specifies the percentage of the between-studies variability in effect sizes that is because of heterogeneity rather than random error, there was a high degree of heterogeneity in the effect sizes, $I^2 = 83.54$. We investigated the source of this heterogeneity through the moderator analyses reported next.

Results of moderator analyses

Task demands. The effect of individual versus team sport was not significant, $Q(1) = 0.11$, $p = .74$. Percentage of variance in performance explained by deliberate practice was 17% for team sports ($\bar{r} = .42$, $p < .001$) and 19% for individual sports ($\bar{r} = .44$, $p < .001$).

The effect of externally paced versus internally paced sport approached but did not reach statistical significance, $Q(1) = 3.13$, $p = .08$. Percentage of variance in performance explained by deliberate practice was 17% for externally paced sports ($\bar{r} = .42$, $p < .001$) and 41% for internally paced sports ($\bar{r} = .64$, $p < .001$). (Sports that are self-paced but highly influenced by opponents' pace, such as running in a race, were not included in this analysis.)

The effect of ball sport versus non-ball sport was not significant, $Q(1) = 0.86$, $p = .35$. Percentage of variance in performance explained by deliberate practice was 20% for ball sports ($\bar{r} = .45$, $p < .001$) and 15% for non-ball sports ($\bar{r} = .38$, $p < .001$).

The effect of open skill versus closed skill sport was not significant, $Q(1) = 0.11$, $p = .74$. Percentage of variance in performance explained by deliberate practice was 17% for open sports ($\bar{r} = .42$, $p < .001$) and 19% for closed sports ($\bar{r} = .44$, $p < .001$).

Participant characteristics. The effect of age was not significant, $Q(1) < 0.01$, $p = .95$. Percentage of variance in performance explained by deliberate practice was 19% for athletes selected from youth teams or youth programs ($\bar{r} = .43$, $p < .001$) and 18% for adult athletes ($\bar{r} = .43$, $p < .001$).

The effect of skill level was significant, $Q(2) = 7.04$, $p = .03$. (Note again that this analysis only included adult athletes.) Percentage of variance in performance explained by deliberate practice was 19% for studies that used subelite athletes ($\bar{r} = .44$, $p < .01$) and 29% for studies that used mixed samples (both elite and subelite athletes; $\bar{r} = .54$, $p < .001$), but it was only 1% for studies that used elite athletes ($\bar{r} = .11$, $p = .50$). See Figure 3.

Research methodology. The effect of method used to measure deliberate practice was not significant, $Q(1) = 0.03$, $p = .86$. The percentage of variance in performance explained by deliberate practice was 19% for studies that used an interview ($\bar{r} = .44$, $p < .001$) and 18% for studies that used a questionnaire ($\bar{r} = .42$, $p < .001$).

The effect of method used to measure performance was significant, $Q(2) = 32.33$, $p < .001$. The percentage of variance in performance explained by deliberate practice was 25% for studies that used group membership ($\bar{r} = .50$, $p < .001$) and 20% for studies that used standardized objective scoring measures ($\bar{r} = .45$, $p < .001$), but it was only 2% for studies that used expert ratings ($\bar{r} = .14$, $p < .01$).

Additional analyses

Individual practice. We conducted three additional meta-analyses. The first included only the 14 effect sizes ($N = 488$) for solitary deliberate practice. We tested this model because there is a debate in the literature about whether deliberate practice must be performed in isolation to be maximally effective (Charness, Tuffiash, Krampe, Reingold, & Vasyukova, 2005; Ericsson et al., 1993). The meta-analytic average correlation between deliberate practice in isolation and performance was .47, 95% CI [.33, .58], which indicates that deliberate practice in isolation explained 22% of the variance in performance, 95% CI [11%, 34%], leaving 78% of the variance unexplained. The percentage of performance variance explained by solitary deliberate practice was not significantly different from the percentage of performance variance explained by practice that was not specified as solitary (18%), $Q(1) = .25$, $p = .62$.

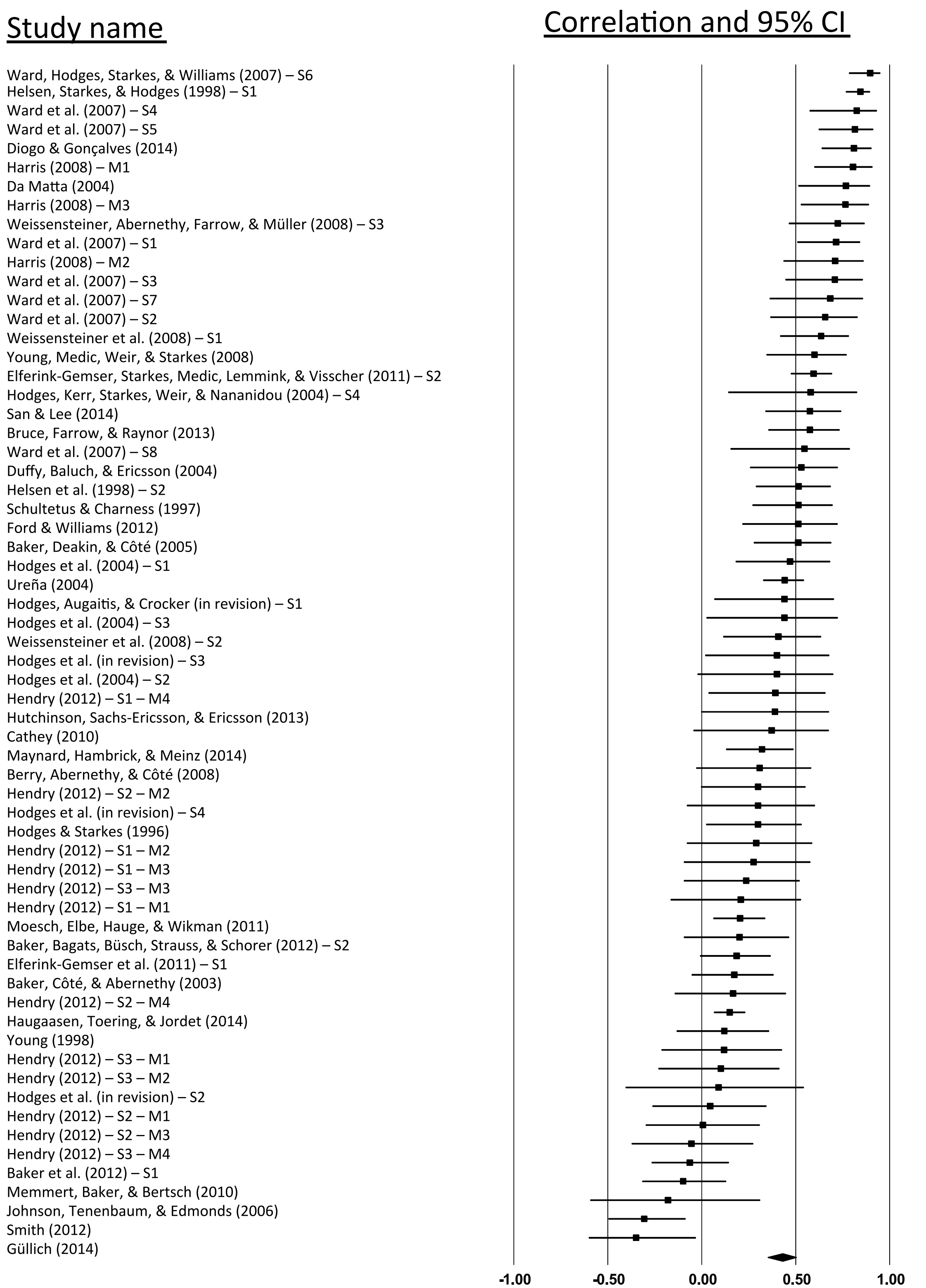

Fig. 2. Correlations between deliberate practice and sports performance. Correlations (squares) and 95% confidence intervals (CIs; lines) are displayed for all effects entered into the meta-analysis. The diamond on the bottom row represents the meta-analytically weighted mean correlation. Multiple measures were adjusted for dependency (see also Methodological Details in the Supplemental Method and Results in the Supplemental Material available online). For studies with multiple independent samples, the result for each sample (S1, S2, etc.) is reported separately. Similarly, for studies with multiple performance measures, the result for each measure (M1, M2, etc.) is reported separately.

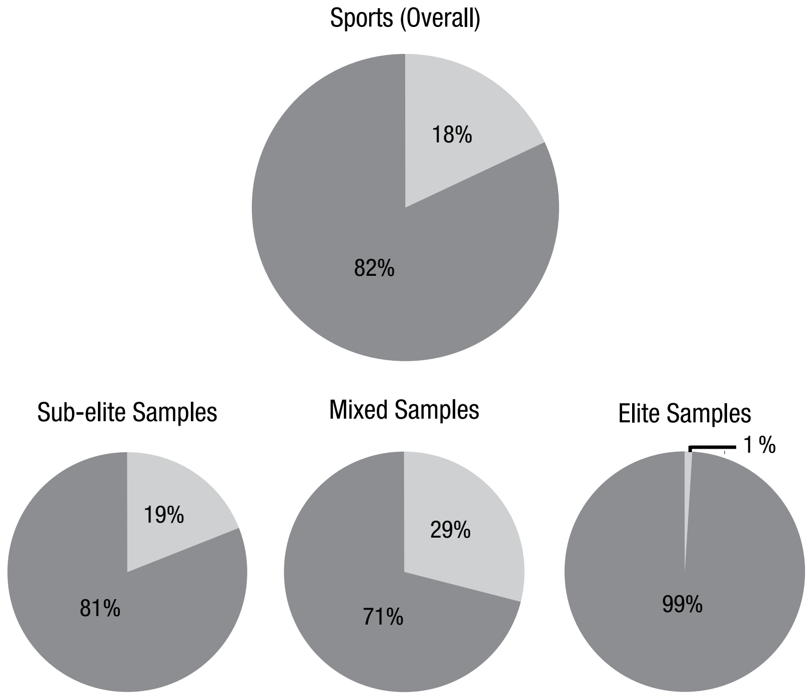

Fig. 3. Percentage of variance in sports performance explained (light gray) versus not explained (dark gray) by deliberate practice (upper panel). Percentage of variance in sports performance explained (light gray) versus not explained (dark gray) by deliberate practice in subelite athlete samples (lower left), in mixed athlete samples (including both subelite and elite athletes; lower center), and in elite athlete samples (lower right). Percentage of variance explained is equal to $\bar{r}^2 \times 100$.

Composite measures. Some of the effect sizes included in this meta-analysis were based on composite measures that included competition or playful activities, along with deliberate practice. Although there is evidence for the importance of both competition and playful activities in developing expertise, both generally and in sports (e.g., Baker, Côté, & Abernethy, 2003; Berry, Abernethy, & Côté, 2008; Bruce, Farrow, & Raynor, 2013; Elferink-Gemser, Starkes, Medic, Lemmink, & Visscher, 2011; Ford & Williams, 2012; Howard, 2012), a central claim of the deliberate practice view is that these forms of domain-relevant experience are less important than deliberate practice as predictors of expertise (Boot & Ericsson, 2013; Ericsson et al., 1993). This claim implies that the average correlation between deliberate practice and performance that we obtained in our overall analysis (see Fig. 2) is a significant underestimation of the true correlation between the variables.

To investigate this possibility, in the second additional meta-analysis, we excluded effect sizes from the aforementioned studies, leaving 53 effect sizes (N = 1,789) based on measures that did not include competition or playful activities. The meta-analytic average correlation for these studies was .41, 95% CI [.33, .50], which is nearly the same as the overall average correlation (.43) and indicates that deliberate practice explained 17% of the variance in performance in this subset of studies, 95% CI [11%, 25%], leaving 83% of the variance unexplained. Moreover, the percentage of performance variance explained by measures of deliberate practice that did not included competition or playful activities was not significantly different from the percentage of performance variance explained by composite measures that did include competition or playful activities, $Q(1) = .28$, $p = .59$.

Starting age. The third additional meta-analysis tested for a difference between higher skill and lower skill performers in starting age. The question of how early a child should begin a sport is of interest to parents, coaches, and expertise researchers alike. Some researchers (e.g., Ericsson et al., 1993) have suggested that an early starting age is critical for attaining an elite level of performance, because the younger the starting age, the greater the opportunity to train. Other researchers (e.g., Baker, 2003; Wiersma, 2000) have argued that starting too young in a sport may be detrimental to later success because it may increase the likelihood of burnout and overuse injuries. Another argument for later specialization is that engaging in multiple sports before focusing on one improves core motor skills and coordination (Fransen et al., 2012).

Starting ages tend to differ across sports. For example, starting age for soccer tends to be earlier than the starting age for wrestling. To control for this in our meta-analysis, we compared the average starting age of higher skill athletes in a given study to the average starting age for the lower skill athletes in that same study. That is, for each study, the effect size was the mean starting age for the higher skill group minus the mean starting age for the lower skill group.

This meta-analysis included 24 effect sizes ($N = 1{,}477$).[3] The higher skill athletes began engagement in their sport later, not earlier, than their lower skill counterparts, although this difference is not statistically significant, $p = .68$. The meta-analytic mean difference in starting age between higher skill athletes and their lower skill counterparts was a nonsignificant 0.11 years (or 5.6 weeks), 95% CI [−.41, .62].[4]

Another question to ask is whether starting age differences are associated with differences in accumulated deliberate practice. In other words, when comparing higher skill to lower skill athletes, does starting age predict the amount of deliberate practice accumulated? To answer this question, we examined all the studies that provided information on skill level, amount of accumulated deliberate practice, and starting age (15 effect sizes, $N = 1{,}137$). We calculated (a) the standardized mean difference between lower skill and higher skill athletes in starting age, and (b) the standardized mean difference between lower skill and higher skill athletes in accumulated deliberate practice. We then calculated the correlation between these two variables. If earlier starting age is associated with more deliberate practice, we should observe a significant negative correlation between starting age differences and deliberate practice differences. However, contrary to this prediction, the correlation was positive and not significantly different than zero ($r = .18$, $p = .53$).

This additional meta-analysis investigating differences between starting age and skill level is not necessarily comprehensive, because we did not conduct a separate literature search for studies of the relationship between these variables. Nevertheless, it provides the most evidence to date on the relationship between starting age and skill level in sports.

Publication-bias analyses

Publication bias occurs when the likelihood of publication depends on the results of the study—that is, when studies that find large and statistically significant effects in the predicted direction are more likely to be submitted and accepted for publication than studies that find small or nonsignificant effects or effects in the nonpredicted direction (Begg & Berlin, 1988; Rothstein, Sutton, & Borenstein, 2005).

We investigated two specific issues pertaining to publication bias. The first was the possibility that studies were missing from our meta-analysis. We found a considerable number of unpublished studies to include in the meta-analysis. However, it is impossible to know whether we obtained all or even most of the unpublished studies that exist. Thus, we investigated the likelihood that our meta-analysis is affected by missing unpublished studies by inspecting a funnel plot depicting the relationship between standard error and effect size (Light & Pillemer, 1984; Sterne & Egger, 2001). If a meta-analysis is unbiased by missing unpublished studies, studies with larger sample sizes (and thus smaller standard errors) will cluster tightly in the plot near the mean effect size, whereas studies with smaller sample sizes (and thus larger standard errors) will be more dispersed and distributed symmetrically about the mean effect size, creating a funnel-like shape. By contrast, if a meta-analysis is likely biased by missing unpublished studies, smaller sample studies will be clustered on the right side of the mean effect size, indicating that these effects are above average in magnitude. This type of clustering suggests that smaller sample studies are more likely to be published (and thus included in a meta-analysis) if they report larger-than-average effect sizes and that their below-average counterparts, which were equally as likely to be found, are missing from the meta-analysis. Inspection of our funnel plot revealed an approximately symmetrical shape, suggesting that studies are not missing from our meta-analysis (See Fig. S13). A trim-and-fill analysis (Duval & Tweedie, 2000a, 2000b) confirmed this, estimating that zero effects were missing from our analysis.

The second issue was the magnitude of the effect size for published versus unpublished studies. Although the preceding analysis estimates that no studies were missing from our meta-analysis, the large number of unpublished studies that we found through our literature searches raises the possibility that certain studies of deliberate practice and sports remain unpublished. Studies may remain unpublished because they are methodologically weak. That is, weak studies may not be submitted for publication or may not "survive" the review process. Alternatively, studies may remain unpublished because they find null or weak effect sizes. That is, studies with results that do not strongly support a particular hypothesis may not be submitted for publication or may be rejected from publication, leading to an inflation of the relationship within the published literature relative to the true relationship.

Weak methodologies and weak findings are not necessarily mutually exclusive. For example, studies with small sample sizes may lack the power to detect a statistically significant effect. This does not seem to be the case within this meta-analysis. The median sample size for the effect sizes from published studies was 33, whereas the median sample size for the effect sizes from unpublished studies was 46. Likewise, when we examined the sample sizes in increments of 10 (i.e., <10, 10–19, 20–29, 30–39, etc.), we found that the majority of the published studies' sample sizes were between 20 and 29, whereas the majority of the unpublished studies' sample sizes were between 40 and 49. (See Table S3 in the Supplemental Materials available online for additional sample-size details of the published and unpublished studies.)

A moderator analysis revealed that the correlations between deliberate practice and performance from the unpublished studies (25 cases, $N = 699$) were significantly smaller than those from the published studies (38 cases, $N = 2{,}066$), $Q(1) = 4.23$, $p = .04$. The average correlation between deliberate practice and performance in unpublished studies was .33, 95% CI [.21, .44], which indicates that deliberate practice explained 11% of the variance in performance in these studies; the average correlation between deliberate practice and performance in published studies was .48, 95% CI [.38, .57], which indicates that deliberate practice explained 23% of the variance in performance in these studies (see Fig. 4).

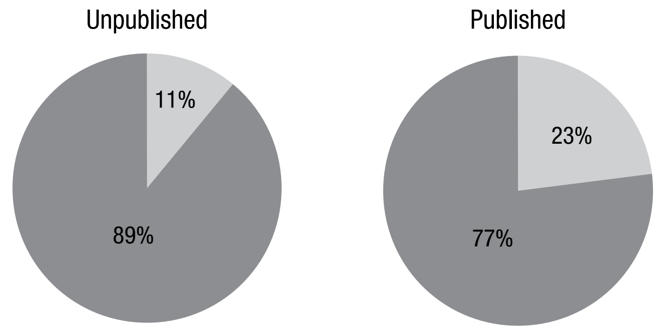

Fig. 4. Percentage of variance in sports performance explained (light gray) versus not explained (dark gray) by deliberate practice in unpublished studies (left) and in published studies (right). Percentage of variance explained is equal to $\bar{r}^2 \times 100$. Any discrepancies between $\bar{r}^2$ values obtained from squaring meta-analytic *r*s and those reported in text are due to rounding; see Supplemental Materials.

General Discussion

The deliberate practice view is an important and influential theoretical account of expert performance (Ericsson et al., 1993), but the claim that individual differences in performance can largely be accounted for by deliberate practice is not supported by the available empirical evidence (e.g., Macnamara et al., 2014). Here, we performed a focused meta-analysis that allows us to draw conclusions about the relationship between deliberate practice and performance in the sports that are represented. By examining currently available evidence, this meta-analysis contributes to a deeper understanding of deliberate practice and its role in acquiring expertise.

We found that, on average, deliberate practice accounted for 18% of the variance in sports performance, leaving 82% of the variance potentially explainable by other factors. Moderator analyses revealed three major findings. First, regarding task demands, deliberate practice explained a similar amount of the variance in performance when comparing individual sports (19%) with team sports (17%); ball sports (20%) with non-ball sports (15%); and open-skill sports (17%) with closed-skill sports (19%). There was a marked trend for deliberate practice to explain more performance variance in internally paced sports (41%) than in externally paced sports (17%). This difference failed to reach statistical significance, though a difference of this magnitude is potentially important from a practical perspective.

Second, regarding type of research method, deliberate practice explained a similar amount of the variance in performance in studies that used an interview (19%) to assess deliberate practice and in studies that used a questionnaire (18%), but it accounted for a much larger amount of the variance in studies when performance was measured using group membership (25%) or a standardized objective score (20%) than when it used expert ratings (2%). It is unclear to us why deliberate practice explained so little of the performance variance when expert ratings were used. Coaches served as the expert raters in all of the studies that used this measure of performance, and 12 of the 14 effect sizes associated with expert ratings were from a single author and were all for youth performance. It is possible that expert ratings by coaches are not reliable when assessing youth athletes or that these particular coaches did not provide reliable assessments. Interrater reliability was high in the two other studies where coaches rated adult athletes, but no interrater reliability information was available for the 12 effect sizes for youth performance. Future research on the relationship between deliberate practice and sports performance would benefit from collecting laboratory measures of performance.

Finally, regarding characteristics of participants, deliberate practice explained a similar amount of the variance in performance for youth athletes (19%) as it did for adult athletes (18%). A major finding of the present meta-analysis was that skill level significantly moderated the relationship between deliberate practice and performance. Deliberate practice explained 19% of the variance in performance in studies that used subelite athletes and 29% of the variance in performance in studies that used mixed samples but a statistically nonsignificant 1% of the variance in studies that included elite athletes. Although more studies are needed that examine the upper echelon of performance (elite category in the present meta-analysis: effect sizes = 6, $N = 228$), this finding suggests that deliberate practice loses its predictive power beyond a certain level of skill. In other words, although there is evidence that deliberate practice is one factor that contributes to performance differences across a wide range of skills, it may not contribute to performance differences at the highest levels of skill. Consistent with this conclusion, in a study of field hockey players included in the present meta-analysis, Güllich (2014) found a nonsignificant difference in accumulated deliberate practice hours between Olympic gold medalists (M = 3,556, SD = 1,134) and field hockey players who played in the first four divisions for their country but who had not achieved international success (M = 4,118, SD = 807). Similarly, in a study of swimmers included in the present meta-analysis, Johnson, Tenenbaum, and Edmonds (2006) found a nonsignificant difference in accumulated deliberate practice hours between highly accomplished swimmers (M = 7,129, SD = 2,604) and swimmers who had not yet achieved similar accomplishments (M = 7,819, SD = 2,209).

Effects of all of the other moderator variables we considered in the meta-analysis were statistically nonsignificant. These null results suggest that the effect of deliberate practice on performance is similar across levels of the moderator variables considered in this study. These findings contribute to a more complete understanding of the relationship between deliberate practice and performance. For example, deliberate practice appears to be as important a predictor of performance for adults as it is for children, at least within sports. As another example, deliberate practice appears to be as important a predictor of performance in team sports as in individual sports.

Across all moderators, the amount of performance variance left unexplained was between 59% and 99%. Some of this unexplained variance presumably reflects measurement error (i.e., the unreliability of the measures), as the degree to which two variables can correlate is restricted by their reliabilities. However, measures of both deliberate practice and performance are typically found to have reasonably high reliability (≥.70). For example, Tuffiash, Roring, and Ericsson (2007) stated that test-retest reliabilities for self-report practice estimates in sports are typically .80 or above. Consistent with this claim, Güllich and Emrich (2014) found that test–retest reliability for amount of practice in field hockey over 3 years was between .80 and 1.00. Furthermore, across a wide range of reliability assumptions, the percentage of variance in performance explained by deliberate practice is smaller than the percentage of variance not explained by deliberate practice[5] (see Table S1 in the Supplemental Materials available online). For example, if reliability of both deliberate practice and performance is assumed to be .80, the mean overall correlation between deliberate practice and sports performance is .53 after correction for unreliability, indicating that deliberate practice accounts for 28% of the reliable variance, leaving 72% explainable by other factors.

Moderator analysis revealed that the effect sizes reported in unpublished studies were significantly smaller than those reported in published studies. Unpublished studies are less likely to be identified through standard literature searches and from being cited in other articles. As an illustration, the published articles in our meta-analysis have been cited over 1,200 times (an average of over 50 citations per article), whereas the unpublished studies have been cited just 30 times (an average of three citations per article; source: Google Scholar).

We also conducted three additional meta-analyses. The first examined practice alone. Practice alone explained 22% of the variance in performance, which was not significantly different than for practice with others (18%). The second additional analysis excluded studies that used a composite measure that reflected not only deliberate practice but also competition or playful activities. For the remaining studies, deliberate practice explained 17% of the variance in performance, which was not significantly different from composite measures that included competition or playful activities (22%). Finally, we investigated the relationship between skill level and starting age. Although there is some evidence that an earlier starting age is associated with superior accomplishment in some domains (e.g., chess; see e.g., Howard, 2012), a major finding in our study was that higher skill athletes did not tend to begin their sport earlier during childhood than lower skill athletes. One possible explanation for this null result is that in sports there is a trade-off between benefits associated with starting earlier and those associated with starting later. In particular, a child starting earlier may benefit from additional time to train, whereas a child starting later may benefit from being physically more mature, which is advantageous in many sports. Also, when comparing higher skill and lower skill athletes, differences in starting ages were not associated with differences in accumulated amounts of deliberate practice. This finding is inconsistent with the argument that earlier starting ages in childhood are associated with higher levels of athletic achievement later on.

Our earlier meta-analysis (Macnamara et al., 2014) was the first large-scale meta-analysis of the relationship between deliberate practice and performance. In the present meta-analysis, we sought to further examine this relationship by focusing on a single domain. Across all factors in our analyses, we found that deliberate practice accounted for less than half of the variance in performance within sports.

What else matters?

The results of this meta-analysis and our previous meta-analysis (Macnamara et al., 2014) provide compelling support for the importance of deliberate practice as a predictor of individual differences in sports performance, but they do not support the claim that deliberate practice largely accounts for performance differences. That is, deliberate practice did not account for nearly all or even the majority (>50%) of the variance in sports performance. What are some of the factors that might account for the unexplained variance?

Evidence from two recent behavioral genetic studies suggests that genetically influenced factors may make an important contribution. In the first study, using a sample with over 850 twin pairs, Hambrick and Tucker-Drob (2014) found evidence for gene–environment correlation in the form of a genetic effect on music practice. However, this could not completely explain genetic effect on music accomplishment. That is, even after statistically controlling for music practice, there was a sizeable and statistically significant genetic effect on music accomplishment. In the second study, Mosing, Madison, Pedersen, Kuja-Halkola, and Ullén (2014) had over 10,000 twins representing an extremely wide range of music skill estimate deliberate practice and perform tests of music aptitude. Mosing et al. (2014) found that there were genetic effects on both music practice and music aptitude. More important, there was no evidence for a causal influence of music practice on music aptitude. Identical twins differing massively in amount of deliberate practice did not differ significantly in music aptitude. Mosing et al. concluded that although some aspects of music expertise clearly require deliberate practice to acquire (e.g., score reading, memorization), at least some basic sensory capacities involved in playing music appear to be unaffected by practice.

Similar evidence for genetic contributions to performance is found in the domain of sports. Behavioral genetic analyses have revealed sizeable genetic contributions to factors involved in athletic performance. For example, in a number of large-scale studies, the genetic contribution to individual differences in VO_2max (i.e., maximum oxygen uptake) and in training-related change in VO_2max has been found to be around 50% (Bouchard et al., 1998; for counterarguments see Ericsson, 2007a, 2007b, 2013). Furthermore, measurement of an approximately 30–gene expression signature predicted gains in VO_2max following endurance training. The RNA expressions for the genes that predicted change in VO_2max were unchanged with training, strongly suggesting that how much one's maximum oxygen uptake will improve with endurance training is preset by genetic variation (Timmons et al., 2010). These differences in response to training have also been found with resistance training (e.g., weight lifting): High responders—those who gained muscle mass easily after engaging in resistance training—had different microRNA expressions than did the low responders—those who gained considerably less muscle mass after engaging in the same resistance training program (Davidsen et al., 2011). Similarly, in a series of molecular genetics studies, North, MacArthur, and colleagues (e.g., Chan et al., 2008; MacArthur et al., 2008; Yang et al., 2003) documented correlations between genotype for ACTN3, which codes the alpha-actinin-3 protein in fast-twitch muscles and performance in "power" sports such as sprinting. Other genetically influenced factors that may contribute substantially to individual differences in athletic performance include ease of gaining muscle mass or ability to maintain leanness (Seeman et al., 1996), white matter integrity (Tomassini et al., 2011), and grey matter density of cerebellar and cortical regions involved in motor control (Tomassini et al., 2011), to name just a few.

In addition to deliberate practice, other forms of experience may contribute to individual differences in performance, including competition experience (Baker et al., 2003) and play activities (for reviews see Côté, 1999; Côté, Baker, & Abernethy, 2007; see also Ford & Williams, 2012; Harris, 2008; Haugaasen, Toering, & Jordet, 2014; though see Hendry, 2012). Somewhat counterintuitively, there is also evidence to suggest that playing multiple sports before specializing in a single sport might positively predict future performance in that sport by improving core motor skills and coordination (Fransen et al., 2012). Later specialization may also reduce the incidence of overuse injuries and psychological burnout, potentially increasing one's ability to attain and maintain expert levels of performance (Baker, 2003; Baker, Bagats, Büsch, Strauss, & Schorer, 2012; Berry et al., 2008; Güllich, 2014; Soberlak & Côté, 2003; though see Ford, Ward, Hodges, & Williams, 2009; Ford & Williams, 2012; Hendry, 2012).

Finally, there are a number of psychological traits that could account for performance differences above and beyond deliberate practice, including confidence (see Craft, Magyar, Becker, & Feltz, 2003, for review), propensity to experience performance anxiety (Chen, Gully, Whiteman, & Kilcullen, 2000), aversion to negative outcomes (Carver & White, 1994), sensitivity to reward (Carver & White, 1994), and cognitive ability factors such as general intelligence (Ackerman, 1987; Gagné, 2013; Schmidt, 2014; Simonton, 2014), working memory capacity (Meinz & Hambrick, 2010), the ability to control attention (Engle, 2002), perceptual speed (Ackerman & Cianciolo, 2000), and psychomotor speed (Ackerman & Cianciolo, 2000).

Future directions

Meta-analyses can be used not only to examine the strength of the relationship between two variables and to identify variables that moderate this relationship but also to empirically evaluate theories (for a review, see Chan & Arvey, 2012). The present meta-analysis is limited by what studies have been conducted to date. For example, not every sport is represented in the meta-analysis. However, assuming appropriate inclusion criteria and systematic procedures are used, meta-analyses should provide the most accurate information about the strength of the investigated effect and about the accuracy of the theory in question. Moreover, meta-analytic results are more generalizable than the results of any one study and thereby contribute to scientific progress in an area.

There are several promising research directions for advancing understanding of expertise. One is to conduct additional studies in areas where research is lacking. This could include studies of deliberate practice in areas (both sports and non-sports) that have not yet been investigated (e.g., the arts.) The results of these studies could then be entered into a meta-analysis to see whether the results change from the present meta-analysis (data available at osf.io/r5qjw). Another direction is to examine the generalizability of the results of the present meta-analysis to other domains, by, for example, testing whether deliberate practice loses its predictive power among elite performers in games, music, art, academics, and professions, as it appears to in sports. Still another direction is to develop finer grained measures of practice and test whether these measures correlate differentially with performance in different types of sports (e.g., open- vs. closed-skill sports) and further investigate the reliabilities of measures of both deliberate practice and performance, because measurement error may attenuate correlations between these measures to a considerable extent.

Finally, we believe that a critical goal for future research is to investigate the relative contributions of multiple factors to individual differences in expertise. Other than deliberate practice, knowledge of factors that contribute to individual differences in expertise is limited, but fortunately there do already exist theoretical frameworks that can guide this research. For example, Gagné's (2013) differentiated model of giftedness and talent (DMGT) posits that individual differences in "competencies" in various domains (technical, arts, science, etc.) arise from multiple variables that develop over time: natural abilities, such as general intelligence and sensory abilities; environmental factors, such as the cultural milieu and family influences; and intrapersonal factors, such as physical health and personality. Simonton (2014) proposed a somewhat similar model to direct research on individual differences in creative performance that posits that both environmental and genetic factors impact creative performance. These multifactor frameworks must be empirically tested (e.g., through structural equation modeling) in order to investigate the relative contributions of these factors and their interactions on skill acquisition and expertise.

Conclusion

To summarize, we found that accumulated amount of deliberate practice is an important predictor of individual differences in sports performance. However, substantially more of the variance in performance was not explained by deliberate practice than was explained by it. We also found that there was no difference in starting age between higher skill and lesser skill athletes.

These findings are important from both a practical perspective and a theoretical perspective. From a practical perspective, knowledge about the contribution of deliberate practice to performance may help people make better informed decisions. For example, athletes, parents, recruiters, and coaches can use this knowledge to weigh the importance of deliberate practice and the associated time and financial investment against the athlete's enjoyment of the sport; the athlete's desire to engage in other forms of domain-relevant experience (e.g., unstructured play with friends, playing other sports); and how well the athlete's physical, cognitive, and psychological characteristics lend themselves to acquiring skill in a given sport.

From a theoretical perspective, our results underscore the importance of thinking broadly about factors that may contribute to individual differences in expertise. The goal now should be to develop theories of expertise that take into account as many potentially relevant factors as possible. To make this a reality, scientists must draw not only from research on skill acquisition and expertise but also from research on cognitive ability, personality, learning, behavioral genetics, and research within the performance domain (e.g., sports science). This effort will shed new light on the origins of expertise.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Supplemental Material

Additional supporting information may be found at http://pps.sagepub.com/content/by/supplemental-data

Notes

1. In our previous meta-analysis (Macnamara et al., 2014), we excluded an effect size (correlation) that did not fall within the valid range [−1.0 to 1.0] (r = 1.15; Law, Côté, & Ericsson, 2007). In the present meta-analysis, we exclude this effect size on the same basis. Note that if we include this effect size, the overall correlation between deliberate practice and performance changes negligibly: $\bar{r}$ = .43 (p < .001, $\bar{r}^2$ = .18) to $\bar{r}$ = .44 (p < .001, $\bar{r}^2$ = .19). For elite athletes, if we include this effect size, this correlation increases from $\bar{r}$ = .11 (p = .46, $\bar{r}^2$ = .01) to $\bar{r}$ = .28 (p = .13, $\bar{r}^2$ = .08), but is still nonsignificant. See Supplemental

Materials available online for complete results with this effect size included.

2. We reversed the sign of the correlation when appropriate before analyzing the data. For instance, negative correlations between deliberate practice and race times indicate that more deliberate practice is associated with faster race times.

3. There was one outlier (an effect size whose residual had a *z* score >3); in this case, athletes in the higher skill group had begun their sport an average of 5 years earlier than the lower skill group (Ward, Hodges, Starkes, & Williams, 2007: U13 athletes). We Winsorized the value to a *z* score equaling 2.99 (−4.19 years).

4. Within the sports science literature, starting age typically refers to the age at which athletes first begin engaging in the sport (e.g., Baker et al., 2005). For three studies, effect size for starting age of serious practice/training was also available. When we use these effect sizes in place of starting age, the pattern of results does not change. The meta-analytic average mean difference was a nonsignificant .35 years (18.2 weeks), 95% CI [−.14, .83], p = .16, indicating that the higher skill athletes began slightly later than the lower skill athletes.

5. The standard formula for correcting a correlation between two variables, x and y, for measurement unreliability is $\hat{r} = r_{xy} / (r_{xx} r_{yy})^{1/2}$, where r_{xx} and r_{yy} are reliability coefficients for x and y, respectively (Schmidt & Hunter, 1999).

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