RUNNING HEAD: Grit and (Deliberate) Practice in Expertise Development

Gritting One's Way to Success – Grit Explains Skill in Elite Youth Soccer Players Beyond (Deliberate) Practice

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ACCEPTED IN PSYCHOLOGY OF SPORT & EXERCISE

Data availability statement

The data and the code used for the analyses can be retrieved from

https://osf.io/djp32/?view_only=dfe743746ff542c89288d118f8a7be81

Abstract

Practice is one of the most important predictors of skill. To become an expert, performers must engage in practice for a prolonged time to develop the psychological characteristics necessary for outstanding performance. Deliberate practice (DP), that is focused repetitive activities with corrective feedback, is particularly beneficial for skill development. The amount of accumulated DP differentiates experts and novices. However, the predictive strength of DP weakens considerably when it comes to differentiating between differently skilled experts, leaving a way clear for other non-practice related factors to exercise their influence. In this paper, we demonstrate using a large sample (388) of elite youth soccer players that one such factor, the personality trait of grit, predicts expertise level both directly and indirectly. Grittier players accumulated more time in coach-led team practice, the activity, which is arguably closest to DP in team sports, which in turn predicted the skill level. Other practice activities, such as self-led training or playing with peers, were not predictive of skill level, neither were they influenced by grit. Grit, however, continued to exert a direct positive influence on the skill level of players even after accounting for the hours of DP accumulated. Overall, a standard deviation of change in the grit score resulted in at least a third of standard deviation improvement in skill. Our findings highlight the need for the inclusion of additional factors in theoretical frameworks in situations where the predictive power of traditional expertise factors, such as practice, is limited.

Keywords: Expertise; Deliberate Practice; Grit; Sport; football; SEM Mediation.

Introduction

To become an expert, immersion in the domain of expertise is necessary. It is no surprise then that practice is often taken to be the main factor driving the acquisition of skill (Bilalić, 2017; Ericsson et al., 1993). In some expertise domains, such as sports, the association between the amount of practice and performance in novices and experts is often over $r = .50$ (Helsen et al., 1998; Ward et al., 2007). However, when we only focus on elite practitioners, the ability of practice to differentiate between more and less skilled experts considerably weakens (Macnamara et al., 2014). In sports, for example, the correlation between practice and performance in elite samples is typically around $r = .10$ (Macnamara et al., 2016; Memmert et al., 2010). The latter finding suggests that other factors, whose influence on skill would be otherwise diminished by practice-related activities in classical expert vs. novice studies, are increasingly important in elite samples. In this paper, we demonstrate that one such factor, the personality trait of "grit", explains skill related differences among a large sample of elite youth soccer players. Grittier youth players accumulated more beneficial types of practice throughout their immersion in the domain, which in turn led to a higher skill level. However, grit differentiated among elite youth players beyond the influence of practice; grittier players were more skilled even when we accounted for the differing amounts of practice. The total effect of grit on skill was considerable – a standard deviation change in grit resulted in more than a third standard deviation improvement in skill.

Deliberate practice (in team sports)

To become proficient in any domain, extensive and prolonged exposure to the associated activities is necessary. All practice activities, however, do not have equal impact on performance. According to the Deliberate Practice framework (Ericsson, 2008; Ericsson et al., 1993), only goal-directed activities that feature repetitions combined with constant feedback aimed at identifying

weaknesses and improving current performance are considered beneficial to performance. It is assumed that engaging in deliberate practice activities is an effective method in acquiring the necessary mental structures that enable expert performance (Ericsson & Pool, 2016). It is not the quantity of overall practice that is crucial, but rather the quantity of focused and effortful (deliberate) practice which differentiates between more and less accomplished individuals (Ericsson et al., 1993). Similar findings have been reported in other domains such as chess (Bruin et al., 2008; Burgoyne et al., 2019; Charness et al., 2005) sports (Ford et al., 2009; Helsen et al., 1998; Hendry et al., 2018; Sieghartsleitner et al., 2018), and education (Nandagopal & Ericsson, 2012; Plant et al., 2005).

However, meta-analyses have reported that (loosely defined) the explanatory power of deliberate practice is considerably less than originally claimed (e.g., from r = .51 in games, to r = .42 in sports, to r = .16 in education; Macnamara et al., 2014, 2016). When the activities were more precisely differentiated between deliberate and other kinds of practice, these estimates of deliberate practice influence improved considerably across expertise domains (r = .42 or 61%; Ericsson & Harwell, 2019). The current controversy on what exactly constitutes deliberate practice (Ericsson, 2020a, 2020b; Ericsson & Harwell, 2019; Macnamara & Hambrick, 2020) highlights inherent difficulties in identifying these activities in some domains. It is possible that an extension of the original definition of deliberate practice is required (for some recent suggestions, see Baker et al., 2020).

Much of the debate about deliberate practice in sport, particularly the monotonic beliefs assumption, stems from translating Ericsson and colleagues' (1993) classic study of musicians to more complex and dynamic domains like sport. In the original study, solitary practice was the prototypical form of deliberate practice. Yet, in interactive, time constrained, invasion sports like

soccer, perceptual, cognitive, and motor systems are concurrently and dynamically challenged. In this sense, training with teammates/opponents in learning environments designed by a coach represent more beneficial practice conditions than a less contextually rich (and considerably rarer) individual training session prescribed by a coach. Such structured interactive "team practice" activities have been shown to discriminate between experts and their less accomplished peers (Baker & Young, 2014; Ford et al., 2009; Helsen et al., 1998; Hodges et al., 2004; Zibung & Conzelmann, 2013).

While it is evident that domain specific practice activity is an important factor in the development of expertise (for reviews, see Baker & Young, 2014; Ford & Coughlan, 2019), it remains unclear whether it is not only necessary, but sufficient (Campitelli & Gobet, 2011; Hambrick et al., 2016). Deliberate practice explains a considerable amount of expert performance, but a large chunk of variance remains unexplained. Even more troubling for the sufficiency claims of deliberate practice is that its explanatory power weakens within elite samples (e.g., Macnamara et al., 2016). The correlation between deliberate practice and performance among heterogeneous samples which include a range of skill levels from novices, through intermediates, to experts, regularly reaches incredible heights (e.g., almost perfect correlation between practice and performance in Ward et al., 2007). However, within the samples of experts, where the differences are considerably smaller, this association often becomes small (Macnamara et al., 2016), or even negative (Güllich, 2014; Johnson et al., 2006). This is certainly a consequence of the restricted range which suppresses relations between variables (Pearson, 1902; Vaci et al., 2014), but it is also an indication that other factors may be at play, in particular at the highest level (Ford & Williams, 2012; Hendry et al., 2018).

Grit and its relation to DP

The personality trait of grit, which corresponds to interest and determination in achieving long-term personal goals (Duckworth et al., 2019; Hodges et al., 2017; Tedesqui & Young, 2018), looks particularly suitable to fill the gap. On the one side, it is theoretically relevant to DP as it may provide the motivational aspect behind this type of practice. There may be no space for talent in the framework of DP, but it leaves the door open for innate factors to indirectly influence the amount of accumulated practice (Ericsson et al., 1993). Some individuals may be more predisposed to put in the hard work associated with DP, which in turn would indirectly affect their skill level (Ericsson & Charness, 1994). More specifically, experts who have a more pronounced personality trait of grit are more likely to spend more time on their chosen activity and persist despite obstacles compared with less gritty peers (Duckworth et al., 2011; Ericsson, 2020b). This is indeed the case in the majority sport domains (Fawver et al., 2020; Larkin et al., 2016; Tedesqui & Young, 2017), but not necessarily all (Tedesqui & Young, 2018). Overall, grit is mostly positively (and moderately) associated with performance in athletes and time spent on practice (for a review, see Cormier et al., 2021). On the other hand, grit explains performance even after one accounts for practice and ability, at least in cognitive domains (Akos & Kretchmar, 2017; A. L. Duckworth et al., 2019; Eskreis-Winkler et al., 2014). In sport domains, grit differentiates between more and less able athletes (Sigmundsson et al., 2020) and retains some of its predictive power within skilled samples (DeCouto et al., 2021; Larkin et al., 2016).

Previous reports have typically focused on the single composite grit score (for a scoping review, see Cormier et al., 2021). Grit is, however, composed of two facets, namely, *Consistency of interests (CI)* and *Perseverance of Effort (PE).* CI refers to continuous interest, throughout time, on a single life-goal instead of focusing on different superordinate goals over short periods of time. PE refers to the ability to maintain effort in the face of difficulties (Duckworth & Quinn, 2009). In

other words, CI represents direction of one's passion, while PE represents magnitude of effort put forward in pursuit of that passion (Tedesqui & Young, 2017). This emphasis on endurance and long-term goals is what differentiates grit from related personality constructs such as self-control and conscientiousness (Duckworth & Quinn, 2009).

The two components of grit may have differing impact on the prediction of success. Recent meta-analysis demonstrated that PE is much more predictive of success in academic setting than CI (Credé et al., 2017). The situation is, however, less clear in sport domains. Some researchers have reported that PE (and not CI) differentiate between skilled athletes of different disciplines, including soccer (Tedesqui & Young, 2017, 2018). Others, however, have reported that both PE and CI are predictive of future success in athletes taking part in the university sports competitions (Ansah & Apaak, 2019) or that only CI is associated with longer tenure for ultramarathon runners (Cousins et al., 2020).

Grit – Practice Interplay (mediation)

The positive association of grit with both practice and skill has consequences for the overall influence of grit on skill in sport domains. There is not only direct impact of grit on skill (relations c in Figure 1A, and c_1 and c_2 in Figure 1B), but also indirectly through (deliberate) practice (relations a and b in Figure 1A, and a_1 / a_2 and b in Figure 1B). The assumption of the interplay between grit and practice follows directly from the literature on DP and grit (Duckworth et al., 2011; Ericsson, 2020b; Ericsson & Charness, 1994; Ericsson et al., 1993). The mediation link between grit and practice has only been formally tested in studies on the spelling bee competitions (Duckworth et al. 2011) and college academic performance (Lee & Sohn, 2017). In both instances, grit did not directly predict success, but rather indirectly through (deliberate) practice. To our knowledge, the assumption of this mediation has not been empirically investigated in sport

domains. The lack of mediation studies precludes us from knowing whether grit influences expertise beyond practice, that is directly in addition to its indirect influence through practice. This is unfortunate since these assumptions carry theoretical importance. For example, the influence of grit on practice would provide a currently lacking explanatory mechanism for differing amounts of practice even among experts (Campitelli & Gobet, 2011; Hambrick et al., 2016).

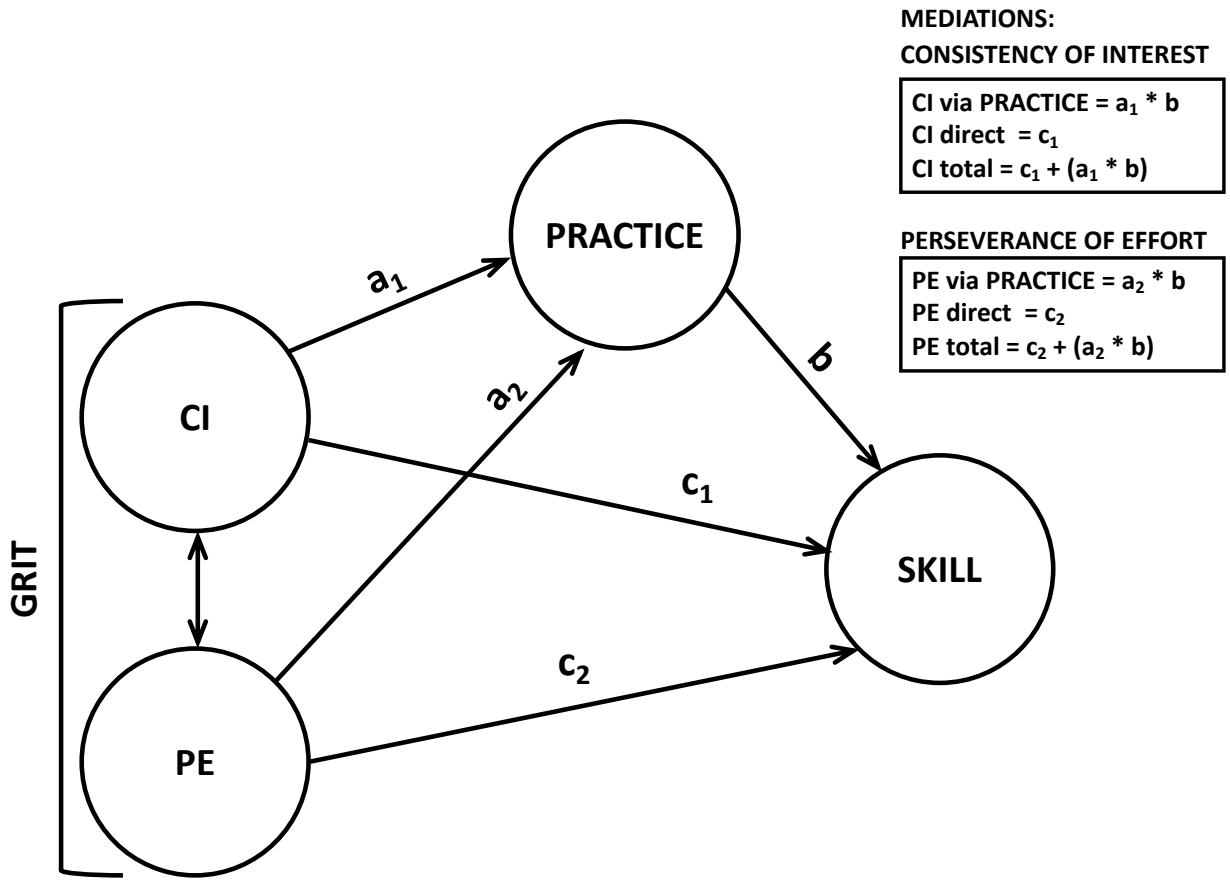

Figure 1. Theoretical model of mediation between grit, practice, and skill. Grit is represented by its two components CI (Consistency of Interest) and PE (Perseverance of Effort). Its influence on Skill is mediated by Practice. The mediation of the CI grit component is the product of the CI relation with practice (a_1) and that of practice with skill (b). The total effect of CI on skill is sum of the direct (c_1) and the indirect, mediation effect (a_1 * b). The mediation of the PE grit component is the product of the PE relation with practice (a_2) and that of practice with skill (b). The total effect of CI on skill is sum of the direct (c_2) and the indirect, mediation effect (a_2 * b).

Current Study

In this study, we examined the relations between practice and grit on the one side, and performance on the other, in a large sample of highly skilled youth soccer players in Australia (Larkin et al., 2016). The players estimated their involvement in different soccer activities retrospectively starting from age eight. One category of activities was *Coach-led (team) practice*, which in our context comes closest to the definition of deliberate practice (Ford et al., 2009; Helsen et al., 1998). The other highly structured activity type was *Competition*, which is considered as highly relevant to development of athletes (Baker, 2003; Ford et al., 2015; Hendry et al., 2019). The other three activity categories, which we call "Unstructured Practice", were *Self-led (individual) practice* (no coach supervision), *Play with peers* (for fun), and *Indirect involvement* (e.g., watching games on TV, playing football video games).

The players also answered questions about their persistence and interest in soccer as part of the grit questionnaire (Duckworth & Quinn, 2009b). Most importantly, they underwent extensive testing of their cognitive and perceptual soccer abilities (e.g., McRobert et al., 2011; Smeeton & Williams, 2012). These non-motor tests feature domain-specific situations which require correct anticipations and regularly correlate highly with objective and subjective measures of skill (Dugdale et al., 2020; Sieghartsleitner et al., 2019). A recent meta-analysis indicates that these domain-specific tests of decision making are by far the best tool among other cognitive tests in differentiating between more and less skilled athletes (Kalén et al., 2021). While they are no perfect measure of skill, the perceptual-cognitive soccer abilities are considered as a proxy for soccer skill in this study.

Based on the Deliberate Practice (DP) framework (Ericsson, 2020b; Ericsson & Harwell, 2019), we expect that coach-led practice influences perceptual-cognitive ability of young elite

soccer players. Competition is also a structured development activity but should be less predictive of skill development as it provides less opportunities for repetitive activities with immediate feedback. Currently, there is limited understanding of the impact of unstructured activities (e.g., self-led training, play with peers, indirect activities) on the development of perceptual-cognitive skills in sports (Ford et al., 2009; Helsen et al., 1998; Hendry et al., 2018; Hodges et al., 2004; Williams et al., 2012; Zibung & Conzelmann, 2013). It has, however, been suggested these unstructured activities may have a positive association with the development of perceptual-cognitive expertise (Roca et al., 2011; Williams et al., 2012).

Grit should positively impact the amount of practice the players accumulated, particularly when it comes to unstructured activities which are under player control. The structured practice (e.g., coach-led training and competition) may be mostly outside of player control, but even there one can assume differences between more and less gritty individuals (e.g., they can attend practice and competitions and give their best). Consequently, we believe that coach-led practice should mediate the influence of grit on perceptual-cognitive ability.

Given the paucity of published reports on the separate components of grit and their inconsistent results (Ansah & Apaak, 2019; Cousins et al., 2020; Tedesqui & Young, 2017, 2018), we consider this study exploratory in nature. Unlike most of the studies, however, we investigate both components simultaneously instead of separately. In order to establish the relative importance of grit's components, it is necessary to introduce both in a single model in order to formally subject them to statistical tests and examine their possible interplay (Credé, 2018).

Method

Participants. Altogether, 388 elite youth male soccer players volunteered to participate. The participants represent the best youth male soccer players in Australia as they were selected by their

regional youth soccer development programs and were competing at national youth soccer championships. They were around 14 years old at the time of testing (M_{age} = 13.8, SD_{age} = .8). Almost all took part in the perceptual-cognitive tests (only six were missing, or 1.5% of the sample), but some did not complete Grit (16 players, or 4%) and/or Practice Questionnaires (between 16 and 25 players, depending on the activity – 4% and 6%). The institutional research ethics board of the University of Sydney approved the study, and the written parental consent was obtained for all participants prior to data collection. The data has been used in another publication, albeit answering differing research questions (Larkin et al, 2016).

Power Analysis. In the Grit – Practice – Performance relation, the association (standardized regression coefficient) between Grit and Deliberate Practice in similar contexts is around .30 (Duckworth et al., 2011; Lee & Sohn, 2017). The Deliberate Practice – Performance association in samples similar to ours, which include elite and sub-elite young practitioners, is around .40 (Hendry et al., 2018; Macnamara et al., 2016). Finally, the direct Grit – Performance relations in similar settings is around .10 (A. L. Duckworth et al., 2011; Lee & Sohn, 2017; Moles et al., 2017). Taking into account these relations, one would need 93 participants to detect the Grit – Practice – Performance mediation with .80 power (Schoemann et al., 2017).

Although the relations of grit's components, CI and PE, and practice on the one side, and performance on the other, are less clear (Ansah & Apaak, 2019; Cousins et al., 2020; Tedesqui & Young, 2017, 2018), we can assume that one component will be stronger than the other in a model where both are entered simultaneously as predictors of DP and skill. CI and PE are correlated at least moderately with each other in studies (average r =.43; Guo et al., 2019), which means that one component, the stronger one, will take over a good share of the explained variance common for both components. Consequently, one can assume that even if the stronger component does not

have the explanatory strength of the full grit concept, it will have a similar impact. For example, if that component is ¾ of the assumed Grit – Practice strength (i.e., ¾ of .30, or .225), we would need 161 participants to detect the Grit's competent – Practice – Performance mediation with .80 power (Schoemann et al., 2017). Even if we assumed that the strength of the grit's competent is just ½ of the grit's (i.e., ½ of .30, or .15), the number of participants which is necessary to detect the mediation with .80 power, 334, is still well within our sample size.

Measures

Grit. Grit was assessed using the child adapted version of the Short Grit Scale (A. L. Duckworth & Quinn, 2009b). The Grit-S (Duckworth & Quinn, 2009), a general personality inventory, is an eight-item self-report questionnaire where the items were answered on a 5- point rating scale from 1 (not like me at all) to 5 (very much like me). Four of the items measure Consistency of Interest (e.g., "New ideas and projects sometimes distract me from previous ones."), while the other four items measure perseverance of Effort (e.g., "I finish whatever I begin"). The overall grit score is normally obtained by averaging the answers on all items.

Considering the recent controversy about the uniformness of the grit concept in general (Credé, 2018; Credé et al., 2017) and sport specifically (Cormier et al., 2019, 2021; Tedesqui & Young, 2017, 2018), we conducted confirmatory factor analysis (CFA). The one factor model (only grit) had a suboptimal fit, while the model with two factors, CI and PE, was clearly superior (see Section 1 in the Supplementary Material, SM). However, even the two-factor model was a good fit. The culprit proved to be one of the questions in the perseverance of effort items ("Setbacks don't discourage me. I don't give up easily."), which had already been identified in other studies as the reason for poor fit (Dunn et al., 2021; Shields et al., 2018; Tedesqui & Young, 2017, 2018). After removing this item, the fit of the model was excellent and significantly better

than when the item was present (see Section 1 in SM). We consequently performed all analyses excluding this item, which was a procedure adopted in other studies (Dunn et al., 2021; Shields et al., 2018; Tedesqui & Young, 2017, 2018).

Practice. The Participation History Questionnaire (PHQ; Ward et al., 2007) was used to document soccer-related activities from age 8 years until the current season. Participants were asked questions relating to the recollection of the number of hours per week and the number of months per year engaged in four soccer-related activities, including match play (i.e., competitive soccer matches), coach- led practice (i.e., soccer practice with a coach), individual practice (i.e., soccer activity by oneself), peer-led play (i.e., soccer activities with peers, including small-sided games), and indirect involvement (activities of non-physical nature, such as playing soccer computer games and watching soccer games).

The CFA of the one-factor model for the five practice activities had a poor fit, confirming that the different types of practice do not belong together (see Section 2 in the SM). A two-factor model fit the data well and was significantly better at describing the observed data than the one-factor model. The first factor was composed of structured activities, namely, Competition and Coach-led training. The unstructured activities (Playing with peers, Indirect activities, and Self-led training) were the content of the second factor.

Perceptual-cognitive Ability. Two tasks were conducted to measure the participant's level of perceptual-cognitive expertise. The first task, decision making, was designed to evaluate participant's ability to make an informed decision of what game action to perform next with reference to the presentation of a sequence of play that was occluded at a key moment. The second task, situational probability, was designed to evaluate each participant's ability to assess soccer-

specific situational information by identifying the likely options for the player in possession of the ball (Williams et al., 2012). For more details, see SM (Supplementary Method).

Procedure

The grit questionnaire was completed first, followed by the PHQ, and the perceptual-cognitive tests. For more details, see SM (Supplementary Method).

Analysis

We used the SEM approach as the variables of interest had two or more indicators/variables. We constructed latent variables for Perceptual-Cognitive Ability out of Decision Making and Situational Probability tests. The grit subscales, Consistency of Interest (CI) and Perseverance of Effort (PE), were made from individual items confirmed by the CFA (see SM, Section 1). Given that the two-factor version of grit is empirically more appropriate (see SM, Section 1), we use both the CI and PE directly in the model, that is without the overreaching grit factor. This approach has been suggested recently because CI and PE can be easily considered as separate concepts (Credé, 2018; Credé et al., 2017). We also provide an alternative model that always featured a second-order latent factor of grit out of these two latent constructs of CI and PE in the SM (see Section 4). This has been a common way of dealing with the grit scale in about two thirds of the studies (for a scoping review, see Cormier et al., 2021).

Finally, the practice latent construct was made from practice activities in a step-by-step fashion. We first use the Coach-led training as the indicator of practice because we expect this kind of activity to be the most predictive of soccer skill based on theoretical considerations (Ericsson, 2020b; Ericsson & Harwell, 2019). The second model adds Competition to the Coach-

led training as part of the practice construct as both activity types are structured activities. The third and final model adds three other unstructured activities as an independent latent construct so that we have two practice types in the model (see Section 2 in the SM for CFA on the practice activities), namely, Structured practice (Coach-led training and Competition) and Unstructured practice (Self-led training, Play with peers, and Indirect Activities).

All measures were normally distributed except the Practice activity, which was positively skewed. To alleviate the non-normality issues in the Practice measures, we log-transformed the variables. Given the small amount of missing data (< 5%), and the fact that the individuals with missing data did not have differing values from the individual with available data on the variables of interest, we assume that the missing pattern was random (Van Buuren, 2018). Consequently, we analyzed the data using standard imputation techniques (Rosseel, 2012). For all three models, we provide Expected Cross-Validation Index (ECVI; Cudeck & Browne, 1983) as the measure of their predictive power, as well cross-validation procedure with Root Mean Squared Error (RMSE) as the main indicator of how the estimates from the training subset fit to the new test subset. In both instances, the smaller the estimates (i.e. closer to 0), the better prediction of the model, with RMSE indices less than .08 considered adequate (Hu & Bentler, 1999).

Results

Descriptive Analysis

The elite players started the activities early, around five years, and by the age of 14 had already accumulated over 5,600 hours of soccer-related activities (see Table 1). Their grit estimates are high (average 3.7 on a 5-point rating scale), while the consistency of interest subcomponent had a lower average than the persistence of effort subscale (3.7 vs. 4.2). The performance on the

perceptual-cognitive ability is generally high as the players correctly answered around two thirds of the problems (see, also Larkin et al., 2016).

The inter-correlations followed the expected pattern. Perceptual-cognitive abilities were significantly related to structured activities (Coach-led Practice and Competition). Unstructured activities (Self-led (individual) Practice, Play, Indirect Involvement) were, however, not significantly correlated to Perceptual-cognitive abilities (except for Indirect Involvement for one of the perceptual-cognitive tests). Grit was associated with both Perceptual-cognitive abilities and practice types. Grit's subscales were related to both Perceptual-cognitive abilities and practice types, but consistency of interest had somewhat higher correlations than the persistence of effort in all instances.

Table 1. The intercorrelations between main concepts: perceptual-cognitive ability (1-2); grit (3); grit's components (4-5); and practice types (6-10).

	1	2	3	4	5	6	7	8	9	10	M	SD
1. Decision Making	—										20.34	4.7
2. Situational Probability	0.28*	—									125.2	11.5
3. Grit	0.15*	0.17*	—								3.7	0.50
4. Consistency of Interest	0.13*	0.16*	0.90*	—							3.4	0.65
5. Perseverance of Effort	0.12*	0.12*	0.72*	0.34*	—						4.2	0.55
6. Coach-led Practice	0.13*	0.14*	0.18*	0.18*	0.11*	—					1003	497
7. Competition	0.12*	0.16*	0.22*	0.24*	0.09	0.42*	—				324	163
8. Self-led Practice	0.03	0.07	0.22*	0.21*	0.14*	0.36*	0.25*	—			794	707
9. Play with Peers	-0.01	0.06	0.15*	0.17*	0.06	0.20*	0.22*	0.55*	—		882	668
10. Indirect Involvement	0.17*	0.09	0.23*	0.24*	0.11*	0.25*	0.33*	0.35*	0.34*	—	2614	2002

Structural Equation Modeling (SEM) analysis

We used Structural Equation Modeling (SEM) to investigate the interplay between practice and grit's two components in respect to perceptual-cognitive ability (see Figures 2 – 4). The

perceptual-cognitive ability was always constructed by two manifest variables (Decision Making and Situational Probability), whereas the grit was represented directly by the components (CI and PE). The CI and PE latent constructs were created from the individual items (see Method). For the Practice construct, we first used Coach-led Practice as it is the closest construct to deliberate practice in our domain. In the second model, we added competition activities to the practice construct (in addition to Coach-led practice) as competition represents another structured activity and was shown to belong together with coach-led practice in an independent CFA (see Section 2, SM). Finally, the third model featured both structured (Coach-led practice and Competition) and unstructured practice (Self-led practice, Play with peers, and Indirect activities) as separate latent factors (again, for a CFA see Section 2, SM). At the end, we provide formal tests between the three models, as well as between coefficients of interest (e.g., CI vs. PE). We depict the standardized coefficients in the figures. The raw estimates and the associated standard errors can be found in the SM, Section 3.

Coach-led practice model. Coach-led practice mediates the influence of Grit on Perceptual-Cognitive Ability (Model 1, Figure 2). It is, however, only the CI and not PE that is being mediated. CI is significantly related the practice (standardized beta, $\beta = .31$; see Section 3 in the SM for raw estimates), while (coach-led) practice in turn directly determined Perceptual-Cognitive Ability ($\beta = .24$). This mediation through practice failed to reach the formal statistical significance level ($\beta = .07$, $p = .066$), as did CI's direct association with skill ($\beta = .26$; $p = .099$). However, when both direct and indirect effects of CI on skill are included, the overall CI's effect on skill ($\beta = .34$) is statistically significant ($p = .04$). In contrast, PE does not affect the practice ($\beta = 0$) and its direct influence on skill ($\beta = .10$) is also not significant. Overall, a change of a standard deviation in the (standardized) grit score leads to a change of more than a third standard deviation in the

(standardized) perceptual-cognitive ability score (more precisely, .34). The impact is even more pronounced when the grit is model as a single-factor construct (.44 – see SM, Section 4).

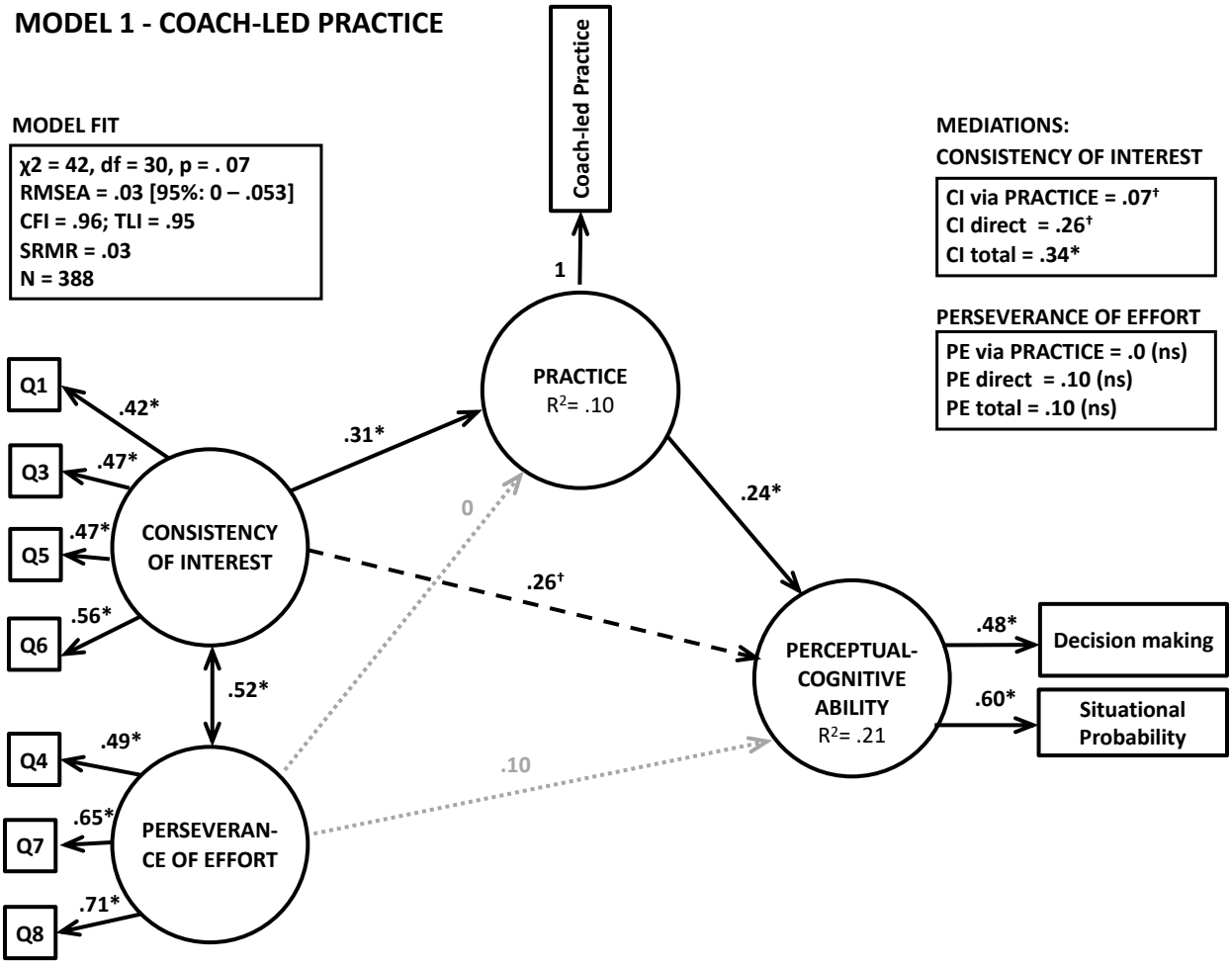

Figure 2. SEM model for Practice defined as Coach-led practice and CI & PE (Model 1). The interplay between Practice, CI, and PE (the predictors) and their influence on Perceptual-Cognitive Ability (dependent variable). Dotted lines indicate non-significant relations, dashed lines borderline significant ones, while full lines indicate significant relations. The numbers on the line are standardized SEM model coefficients. The indirect influence of CI and PE on Perceptual-Cognitive Ability through Practice is formally tested in a mediation model (upper right box). Model fit indices are presented in the upper left box. *$p < .05$, †$p < .10$.

Coach-led practice + Competition model. We extended our initial model by adding Competition, another structured practice, to the latent construct of Practice (Figure 3). The results are like those found in Model 1. Figure 3 shows that only CI is a significant predictor of practice ($ß = .49$), whereas the PE does not significantly predict how much players will practice ($ß = -.06$; $p = .63$).

Consequently, only CI has a significant indirect effect on skill through practice (*ß* = .17; *p* = .049). The direct effect of CI on skill (*ß* = .19) was not significant (*p* = .35), but the overall effect of CI on skill, which includes the direct and indirect effects, was large (*ß* = .36) and significant (*p* = .038). A change of a standard deviation in the (standardized) CI score leads to a change of more than a third standard deviation in the (standardized) perceptual-cognitive ability score.

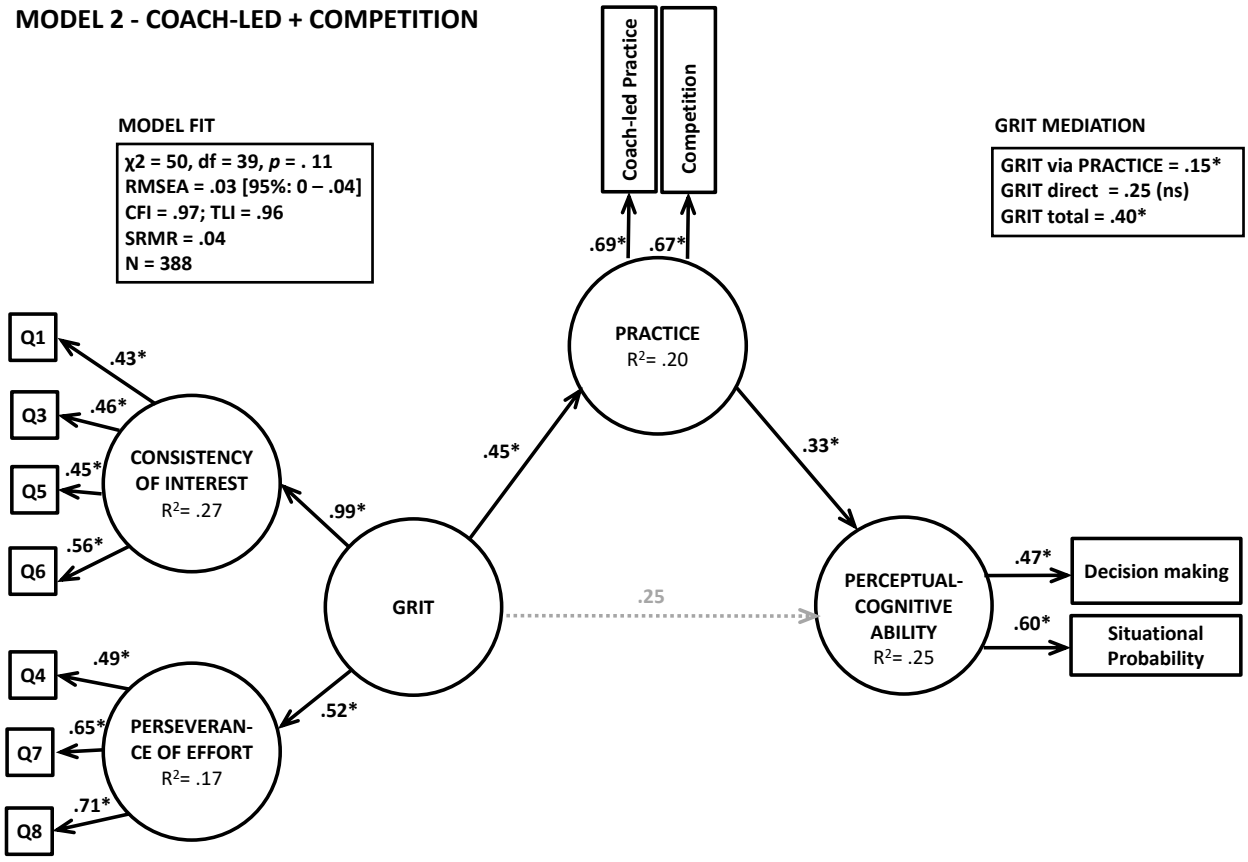

Figure 3. SEM model for Practice defined as Coach-led practice + Competition and CI & PE (Model 2). The interplay between Practice (Coach-led practice and Competition), CI, and PE (the predictors) and their influence on Perceptual-Cognitive Ability (dependent variable). Dotted lines indicate non-significant relations, dashed lines borderline significant ones, while full lines indicate significant relations. The numbers on the line are standardized SEM model coefficients. The indirect influence of CI and PE on Perceptual-Cognitive Ability through Practice is formally tested in a mediation model (upper right box). Model fit indices are presented in the upper left box. *$p < .05$.

Structured and unstructured practice model. Finally, the last model included the unstructured practice activities (self-led practice, play with peers, and indirect activities) in addition to the

structured practice activities. Model 3 had two latent practice constructs which were predicted by grit, and which predicted perceptual-cognitive ability (Figure 4). Only CI was a significant predictor of structured (*ß* = .47) and unstructured practice (*ß* = .41). Only the structured practice in turn was predictive of skill level (*ß* = .38). Consequently, the CI's impact on grit was mediated only through the structured practice. The mediation effect (*ß* = .17) was not quite significant (*p* = .065), like the direct CI's effect on skill (*ß* = .17; *p* = .32). The overall CI's effect on skill (*ß* = .35), which includes both direct and indirect effects, was also not quite significant (*p* = .051).

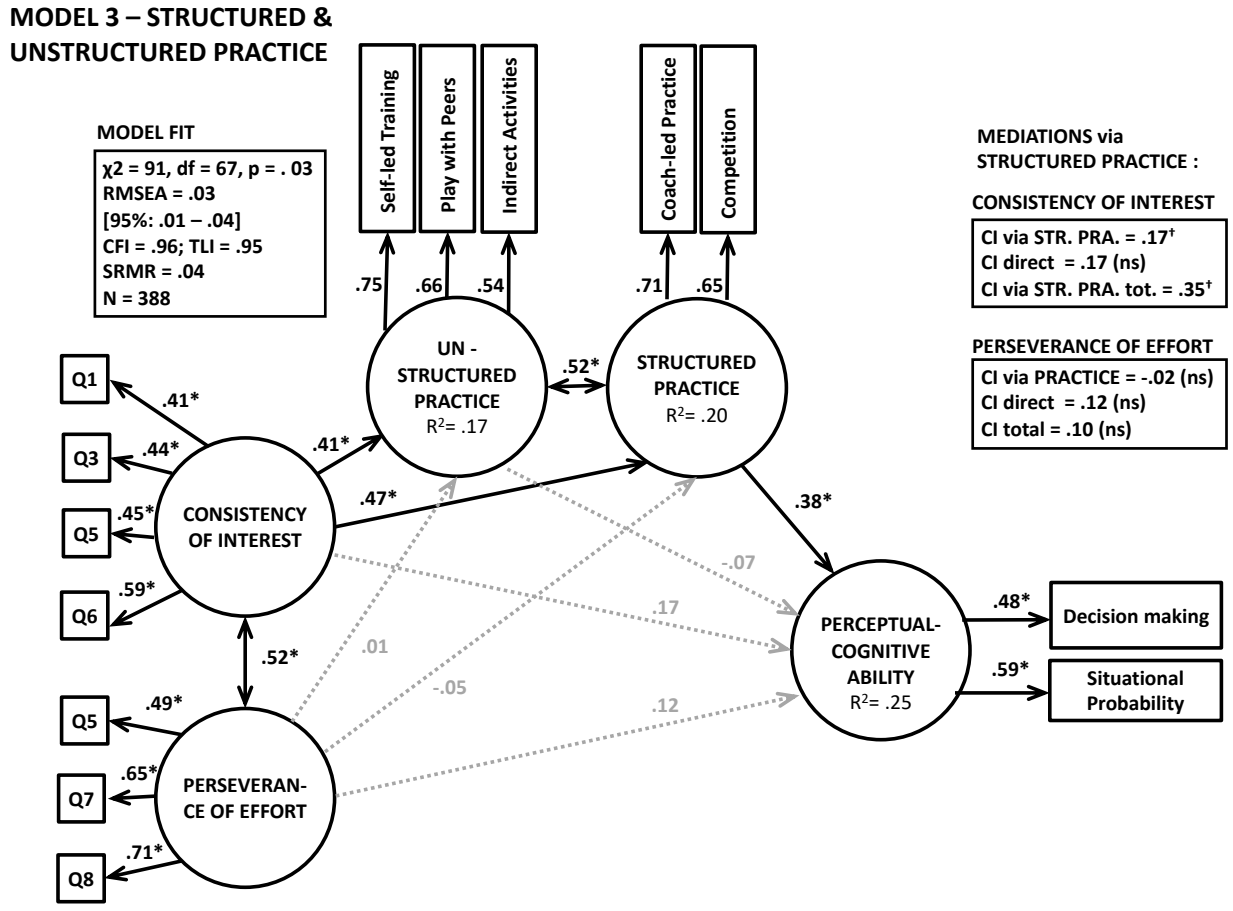

Figure 4. SEM model for Practice defined as Coach-led practice + Competition and CI & PE (Model 3). The interplay between Structured (Coach-led practice and Competition) and unstructured Practice (Self-led training, Play with peers, and Indirect activities), and CI and PE (the predictors), and their influence on Perceptual-Cognitive Ability (dependent variable). Dotted lines indicate non-significant relations, dashed lines borderline significant ones, while full lines indicate significant relations. The numbers on the line are standardized SEM model coefficients. The indirect influence of CI and PE on Perceptual-Cognitive Ability through Structured Practice is formally tested in a mediation model (upper right box; mediation through Unstructured Practice not shown as it is negligible and not significant). Model fit indices are presented in the upper left box. **p* < .05, †*p* < .10.

Comparison between models. There were some differences between the three models. The first two models had an excellent fit, while the third model, with structured and unstructured practice, had merely a very good fit (see Model Fit box in Figures 2 through 4, left upper corner). One goodness of fit metric, namely χ^2, indicated that the predicted and observed data were equal for the first two models (e.g. χ^2 was not significant). The same metric was significant for the third model, which means that the model-predicted and observed were significantly different. Formal tests also indicated that the first and second models were better fitting than the third model, but only the difference between the second and third reached the significance level ($\chi^2 = 49.6$, df = 37, $p = .08$ and $\chi^2 = 43.8$, df = 29, $p = .04$ for the first versus third, and second versus third models, respectively). The difference between Model 1 (practice as coach-led training) and Model 2 (practice as coach-led training and competition) was negligible ($\chi^2 = 7.5$, df = 8, $p = .48$). Finally, Model 1 and Model 2 had a better predictive power (ECVI = .288 and .328, respectively) than Model 3 (ECVI = .503). While Model 1 and 2 should be considered superior to Model 3, it should be noted that the cross-validation procedure indicated that all three models generalize well to new data (RMSE < .06 for all three models – see SM, Section 3).

Consistency of Interest (CI) vs. Persistence of Effort (PE). The CI was consistently a more significant predictor of practice (and sometimes perceptual-cognitive ability) than PE. One should not, however, assume that the CI was a significantly stronger predictor than PE. For that statement, one would not only need to check the significance in relation to other constructs (e.g., CI is a significant overall predictor of skill, whereas PE is not), but one would need to: a) compare the actual coefficients of the two constructs directly; or b) compare models with one concept and without the other. Our SEM models allow for such direct comparisons of either coefficients or differing models. Although the differences between CI and PE's overall influence on skill are

considerable (e.g., .34 vs. 10 in Model 1B – see SM, Section 4) they are not consistent enough to produce statistical significance in any of the three models (p between .10 and .20 – see SM, Section 4). Similarly, when we estimate Model 1 (or Model 2 and 3) with CI and without PE, as well as with PE and without CI, the two models are not significantly different (p between .08 and .30).

Discussion

We report that the personality trait of grit has a sizable influence on the development of expertise in soccer mostly through its CI component. A CI grit score higher of only a standard deviation leads to more than a third standard deviation better performance score. The impact is even more pronounced when both grit components are considered as a single construct – almost half a standard deviation. CI's influence on skill is both direct (.19 / .36 = 53%) and indirect, through (deliberate) practice (.17 / .36 = 47%). Youth soccer players who display consistent interest tend to be more skilled and accumulate considerably more highly structured and effortful practice than their less gritty peers. The accumulated structured practice then determines the level of perceptual-cognitive ability because the players who spent more time on soccer-related activities demonstrated higher levels of perceptual-cognitive skill.

Grit's role in development of (motor) skill

The indirect influence of grit on expertise through practice is predicted both through theory and empirical work (A. L. Duckworth et al., 2011; Ericsson et al., 1993). Gritty players spend more time on domain-related activities, particularly those important for skill acquisition as they tend to be less inherently enjoyable. This behavior in turn leads to the acquisition and development of mental structures that enable outstanding performance (Ericsson & Pool, 2016). The effect of grit in our study is remarkable not only because it is large (.44 and .36 for the whole grit construct and CI, respectively), but also because it differentiates within elite (youth soccer) players. One possible

explanation for such a large effect is that small initial differences can snowball to large effects over time. Grittier players probably continuously log more time than their less persistent peers. The differences may not be large at the beginning, but with time, they become more visible. By the time they are teenagers, the accumulated hours under the influence of grit differ even among the very best athletes in the country.

Arguably, the most important result of our study was that the motivational-personality factor of grit influenced the skill level among elite youth soccer players even after we accounted for the influence of practice. The extent of grit's influence was considerable and comparable to that of practice, which is regularly a primary determinant of skill level (Ward et al., 2007). Other studies have found that grit incrementally predicts achievement over and above the influence of other factors (Akos & Kretchmar, 2017; A. L. Duckworth et al., 2007; Eskreis-Winkler et al., 2014). However, none of these studies looked for mediated effects of time on the performance. The exceptions are the studies on contestants in the spelling bee contest (A. L. Duckworth et al., 2011) and college academic achievement (Lee & Sohn, 2017), which both found that grit's effect on performance is mediated through deliberate practice. In contrast to our study, the direct relation between grit and performance was not significant once we accounted for (deliberate) practice.

How does a psychological factor influence expertise directly? One possibility is that grit affects performance through the influence of another cognitive factor that we have not considered in our study. Grittier players, for example, may engage more in metacognitive processes than their less accomplished peers, reflecting upon and evaluating decisions made in training sessions as a means of analyzing and ultimately improving performance (Jonker et al., 2012). These metacognitive processes then influence performance. Another possibility is that coaches prefer grittier players and consequently support them by involving them more into structured activities

than their less gritty peers. This mechanism would then explain why grittier players still accumulate more structured activities, such as coach-led practice and competition, although these kinds of activities are mostly outside their control at that age.

Consistency of Interest (CI) and Perseverance of Effort (PE)

Unlike most of the studies involving grit (for a review, see Cormier et al., 2021), we investigated both grit as a unified single measure, and CI and PE separately as grit's components. In the latter instance, we featured both CI and PE in a single model (instead of separately assessing them), which enabled us to directly compare their influence. Our analyses show that CI is a better predictor of both (deliberate) practice and skill than PE. CI had higher simple correlations with practice and performance indicators than PE (see Table 1), as well as considerably higher overall influence (direct + indirect) on skill (.34 vs. 10 in Model 1; .31 vs. .10 in Model 2). The overall effects of CI on skill were significant, unlike those of PE (see Figure 3 and 5). However, when the influence of CI on skill was formally compared to its PE counterpart, the differences were not statistically significant either when they were directly compared or when the models with and without the individual components were pitted against each other (see online SM).

It is noteworthy that our finding of CI being seemingly more important than PE contrasts the current trend of research on these two components of grit (Credé et al., 2017). PE is the sole predictor of success in academic settings (Crede et al., 2017) and has been shown to differentiate between differently skilled athletes (Tedesqui & Young, 2017, 2018). One possible explanation for the trend in our study is that the soccer players were all around 14-15 years of age, unlike in most of the other studies which featured older participants. According to the early diversification pathway in Cote's developmental model of sport participation (Côté, 1999; Côté & Vierimaa, 2014), athletes of that age would be making the transition from "sampling years" during childhood

(6-12 yrs.) to the "specialization" years during adolescence (13-18 yrs.). During the sampling years, where children are exploring different sports and developing interest in sport engagement CI would then be a prime candidate for developing skill through consistent interest in the sport activity. In contrast, during the specialization phase, when developmentally elite players focus on more complex and demanding forms of practice in a single sport, PE may exert more of its influence.

(Deliberate) Practice in sports

Grit only exerted influence through highly structured practice such as team training led by a coach (see Figure 2 and 4). This is not an unexpected finding given that this kind of practice is most challenging (Hendry et al., 2019), something that grittier players should deal with easier than their less gritty peers. This kind of highly structured practice was predictive of the soccer skill, which calls for rethinking the definition of deliberate practice in certain domains. Team training led by a coach is obviously not solitary training, designed and monitored by a coach who provides feedback, which would constitute the classical definition of deliberate practice (Ericsson, 2020b; Ericsson et al., 1993). However, team training led by a coach is arguably more related to performance than individual training with a coach (Hendry & Hodges, 2018). Interactive practice with other team members under corrective supervision of coaches is essential to acquire the mental structures necessary for developing skill. It is no wonder then that the interactive team training has been regularly shown to be an important factor in determining skill in team sports (Ford et al., 2009; Helsen et al., 1998; Hendry & Hodges, 2018; Hodges et al., 2004; Starkes et al., 1996; Zibung & Conzelmann, 2013) and as such, it should constitute a part of deliberate practice activities in team sports.

A few practice activities, such as playing with peers, watching soccer on TV (Indirect Involvement), and even self-training (self-led individual practice) were not predictive of soccer skill (see Figure 6 and 7). None of these activities involve the necessary immediate augmented feedback, which is prerequisite for successful learning (Bilalić, 2017; Ericsson et al., 1993). They are much less effortful than interactive team practice, which is reflected in the smaller influence of grit on the unstructured practice compared to the structured practice. It is expected that they are not going to be relevant in differentiating between skill levels of a homogenous elite sample, as was the case in our study. What was less expected is that the actual time spent in official competitions was highly predictive of soccer skill. The finding runs counter to the deliberate practice framework as in official competitions there should not be enough opportunities for repetitive-corrective practice of certain weaknesses (Ericsson et al., 1993).

Limitations

Despite the predictive power of the grit concept in this study, a couple of critical issues should be noted. Grit and its components were captured poorly (see, for example, R^2 for PE in Figures SM3 – 5), with the consequence that even large differences between CI and PE did not reach statistical significance level due to the associated variance. When the composite scores were used in a path analysis, instead of the latent construct in SEM presented here, the size of all relations increased for about a third and considerably improved their statistical significance (see Section 5 in the SM). Consequently, researchers should consider using appropriate statistical tools, such as SEM, which account for the unreliability in the actual measurements of the constructs.

Personality traits tend to be stable during the childhood (Hampson et al., 2007; Harris et al., 2016) but there is a tendency for increase in the grit trait as children grow older (Duckworth, 2016). It is unclear how this overall increase in the grit scores affects individual athletes. For

example, more skilled players may inevitably become grittier than their less skilled peers due to positive reinforcement of success (Jiang et al., 2019). In future, researchers should consider the dynamic interplay between grit on the one side, and practice and skill on the other, by measuring grit, in addition to practice and skill, on multiple occasions throughout skill acquisition process.

Grit's indirect impact on skill through practice poses the question of how other potential motivational aspects would fare in explaining the skill acquisition process. Grit's long-term component differentiates it from several other personality-based constructs (Duckworth & Quinn, 2009), but some measures of motivation overlap with grit in temporal aspects. For example, achievement motivation with its goal structures (Eccles & Wigfield, 2002) not only features long-term goals, but also predicts performance in sports (Müller & Cañal-Bruland, 2020). Grit may have motivational properties, but it is still considered as a personality trait (Duckworth, 2016). Therefore, grit is often theoretically considered a predecessor of motivational aspects, including achievement goals (Datu, 2021). Empirically, it is different from (future-oriented) motivation (Muenks et al., 2018) and the research in academic setting indicates that achievement goals mediate grit's influence on success (Alhadabi & Karpinski, 2020; Chen et al., 2018; Datu et al., 2018). Given that achievement goals on their own are unlikely to be the direct cause of success, it would be important to include practice, as a way of acquiring mental structures necessary for expertise development, into the causal process.

Conclusions

Our results highlight the importance of motivation and personality factors in expertise. The trait of grit had overall similar impact on the performance of elite youth soccer players as (deliberate) practice itself. Yet, the relative unreliability of the grit scale may preclude practitioners from its inclusion in their talent identification and development process assessments. The results,

576 however, point that in elite samples where classical factors such as practice and talent indication
577 may explain only a small chunk of performance, other motivational and personality factors should
578 be considered.

579

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586 **Additional Information**

587 Supplemental Material (SM)

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589

590 **Data availability statement**

591 The data and the code used for the analyses can be retrieved from
592 https://osf.io/djp32/?view_only=dfe743746ff542c89288d118f8a7be81

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Supplemental Materials for

Gritting One's Way to Success – Grit Explains Skill in Elite Youth Soccer Players Beyond (Deliberate) Practice

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This PDF file includes:

Supplementary text
Tables SM1 to SM6
Figures SM1 to SM6

SI References

Other supplementary materials for this manuscript include the following:
https://osf.io/djp32/?view_only=dfe743746ff542c89288d118f8a7be81

Supplementary Information Text

Supplementary Method

Practice. An adapted version of the Participation History Questionnaire, PHQ (Ward et al., 2007), was used to gather data relating to date of birth and soccer-related activities that players had undertaken from the current season back to 8 years of age. The questionnaire elicited information relating to the number of hours participants engaged in soccer-related activities at a specific age. Participants were asked questions relating to the recollection of the number of hours per week and the number of months per year engaged in four soccer-related activities, including match play (i.e., competitive soccer matches), coach- led practice (i.e., soccer practice with a coach), individual practice (i.e., soccer activity by oneself), peer-led play (i.e., soccer activities with peers, including small-sided games), and indirect involvement (activities of non-physical nature, such as playing soccer computer games and watching soccer games).

Perceptual-cognitive Ability. A film-based paradigm using the temporal occlusion method was used to determine perceptual-cognitive ability. Two activities were conducted to measure the participant's level of perceptual-cognitive expertise. The first activity, decision making, was designed to evaluate participant's ability to make an informed decision of what game action to perform next with reference to the presentation of a sequence of play that was occluded at a key moment. The decision-making activity presented 20 video clips of offensive soccer sequences. Participants were instructed to watch the clip and at the point of occlusion make an informed decision regarding the next game action if they were the players on the ball (i.e., What would you do next?). Participants were informed that there were three possible decision outcomes: (a) pass the ball; (b) run with the ball; or (c) shoot at goal. To demonstrate the response, a picture of the last frame of the video was provided to the participants who were asked to indicate the game action (i.e., run with the ball, pass, or shoot) and the direction in which the game action would take place (i.e., draw an arrow in that direction). This procedure is consistent with the protocol used in previous research (Roca et al., 2012; Ward & Williams, 2003). Each trial was scored out of 2, with 1 point being allocated for the correct direction (as indicated by the arrow) and 1 point for indicating the correct game action (i.e., pass, run, or shoot). A total score of 40 points was possible, with the total score for all trials being used for analysis purposes.

The second activity, situational probability, was designed to evaluate each participant's ability to assess soccer-specific situational information by identifying the likely options for the player in possession of the ball (Williams et al., 2012). The situational probability activity presented 20 video clips of an evolving passage of play for approximately 6 to 10 s, and at a critical moment in the footage, 120 ms prior to the player in possession of the ball making a pass, the footage was frozen. This last frame was presented for 15 s. During this time, participants were required to indicate, on an

image of the last video frame, the three most threatening players to the defence, if they were to receive the ball next. Then participants were asked to rank the identified players from one to three in order of most threatening (i.e., 1) to the defensive team to least (i.e., 3) threatening. Each trial was scored out of 10 points, with the scoring weighted to reward correct responses. The correct identification of the most threatening player scored 6 points, second most threatening scored 3 points, and the third most threatening player scored 1 point. When a participant identified an option as being higher or lower than the identified correct ranking by expert coaches (n = 5), the total available points were subtracted by the participants' ranking of the player. Therefore, if a participant identified the top-ranked player as the third most threatening player, the participant would receive 3 points for that player (6 – 3 = 3). The total score for all trials were calculated for analysis.

Procedure. Participants first completed the Grit-S with the completion time ranging from 5 to 10 min. The PHQ was then administered, with participants taking approximately 1 hr to complete. Finally, participants completed the perceptual-cognitive activities. The decision-making activity was completed first, followed by the situational probability. Prior to each activity three familiarization trials were presented to ensure that participants were comfortable with each of the tasks. The activities were projected on a screen (2.1 m), with participants seated within a clear view of the screen (approximately 5–7 m away).

Supplementary Results

1) Confirmatory Factor Analysis for Grit Scale

We used the short Grit scale (REF), which has eight items, four for each of the two grit's components: Consistency of Interest (CI) and Perseverance of Effort (PE).

The four items for CI are:

Q1. New Ideas Distract Me from Previous Ones

Q3. I Have Been Obsessed with A Project for a Short Time but Lost Interest

Q5. I Often Set a Goal but Later Choose to Pursue a Different One

Q6. I have difficulty Maintaining Interest in a Projects Longer than a Few Months

The four items for PE are:

Q2. Setbacks Don't Discourage Me

Q4. I am Hard Worker

Q7. I Finish Whatever I Begin

Q8. I am Diligent

We performed a confirmatory factor analysis on the grit scale in the statistical program R with with lavaan package (Rosseel, 2012). First, we constructed a one-factor model where all the items load onto a single (grit) construct (Figure SM1A). This model had a bad fit (see the box Model fit in Figure SM1A). The two-factor model, where one half of the items were loading on the CI and the other half of the items on the PE, had a much better fir (Figure SM1B). The formal test of how the model fit indicated that the two-factor model had a significantly better fit ($\chi 2 = 838$, df = 1, $p < .001$). The two-factor model was, however, not describing the data particularly well (see Model fit box in Figure SM1B). The main problem appeared to be Q2, which had a poor loading on PE (only .25). Once Q2 was left out and only other three items were forming the PE concept, the revised model improved (Figure SM1C). The revised two-factor model (Figure SM1C) had a significantly better fit than the original two-factor model with Q2 (Figure SM1B) – $\chi 2 = 38$, df = 6, $p < .001$. We have consequently used the revised two-factor model in our main analyses.

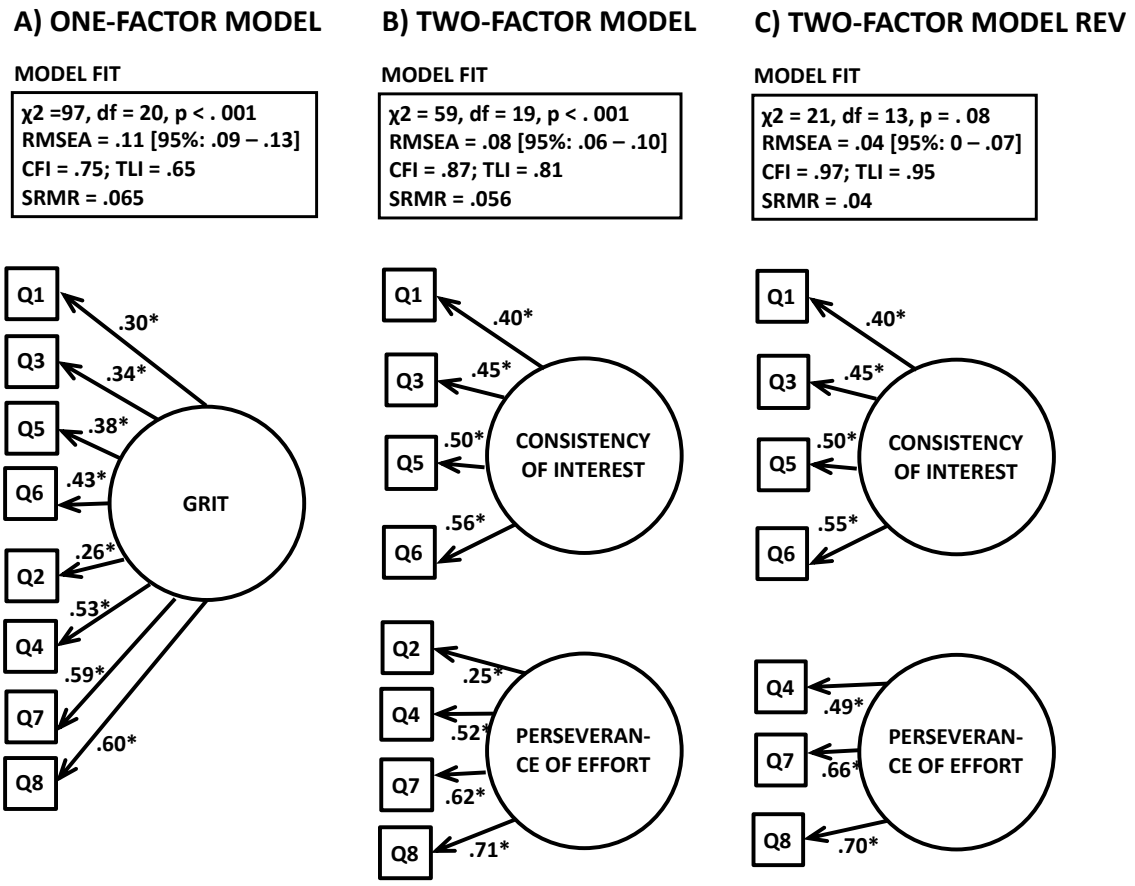

Figure SM1. CFA on Grit Scale. A) One-factor model where all items load on the single construct. B) Two-factor model where CI and PE constructs are identified separately. C) Revised two-factor model without Q2 in PE.

1) Confirmatory Factor Analysis for Practice Activities

The five practice activities were also subjected to the CFA. The first model where all practice activities load onto a single practice factor had a bad fit (One-Factor Model in Figure SM2A). When the assumed distinction between structured and unstructured practice was introduced, the two-factor model fit the data significantly better ($\chi 2 = 40$, df = 1, $p < .001$).

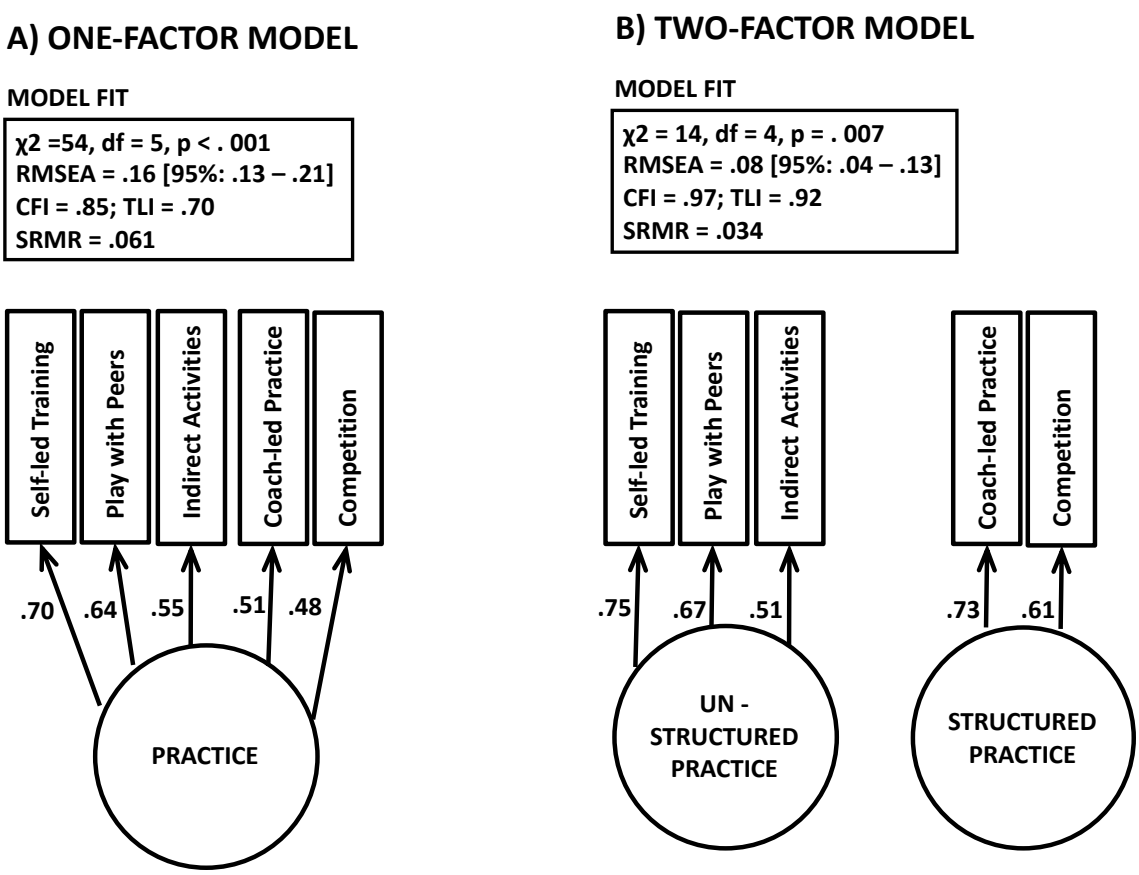

Figure SM2. CFA on practice activities. A) One-factor model where all items load on the single construct. B) Two-factor model where structured and unstructured practice activities are identified separately.

2) Main SEM Analyses

The SEM analyses presented in the main text were conducted in R with lavaan program (Rosseel, 2012) using case-wise (or 'full information') maximum likelihood estimation.

Table SM1 provides the coefficients with SE for the model which features Coach-led (team) practice activities with CI and PE as separate constructs – see Model 1 and Figure 2 in the main text.

Table SM1. Model 1 – Practice represented as Coach-led (group) practice with CI and PE.

Latent Variables:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Interest =~						
Q1.NwIdsDsMFPO	1.000				0.358	0.423
Q3.IHvBOAPSTLI	1.343	0.288	4.658	0.000	0.481	0.465
Q5.IOfSGBLCPDO	1.332	0.301	4.424	0.000	0.477	0.466
Q6.IhvdfMIPLFM	1.691	0.357	4.738	0.000	0.605	0.563
Perseverance =~						
Q4.IamHardWrkr	1.000				0.327	0.493
Q7.IFnshWhtvrB	1.552	0.256	6.058	0.000	0.508	0.652
Q8.IamDiligent	1.537	0.237	6.490	0.000	0.503	0.707
PER =~						
DM_Total	1.000				2.262	0.480
SP_Total	3.056	0.965	3.168	0.002	6.915	0.597
PRACTICE_str =~						
Trainng_cch_lg	1.000				0.232	1.000

Regressions:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
PER ~						
Interest (c)	1.678	1.016	1.652	0.099	0.265	0.265
Persevrnc (c1)	0.660	0.938	0.704	0.482	0.095	0.095
PRACTICE_ (b)	2.332	0.997	2.338	0.019	0.239	0.239
PRACTICE_str ~						
Interest (a)	0.200	0.075	2.649	0.008	0.307	0.307
Persevrnc (a1)	0.004	0.071	0.063	0.950	0.006	0.006

Covariances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Interest ~~						
Perseverance	0.062	0.017	3.662	0.000	0.529	0.529

The second model, which was used using the same parameters as the first, added another structured practice activity, Competition, to Model 1. The results of the second model (Model 2, Figure 3 in the main text) can be found in Table SM2.

Table SM2. Model 2 – Practice represented as Coach-led (group) practice + Competition with CI and PE.

Latent Variables:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Interest =~						
Q1.NwIdsDsMFPO	1.000				0.365	0.433
Q3.IHvBOAPSTLI	1.317	0.276	4.779	0.000	0.481	0.466
Q5.IOfSGBLCPDO	1.254	0.282	4.455	0.000	0.458	0.449
Q6.IhvdfMIPLFM	1.644	0.338	4.864	0.000	0.601	0.560
Perseverance =~						
Q4.IamHardWrkr	1.000				0.325	0.490
Q7.IFnshWhtvrB	1.563	0.259	6.044	0.000	0.508	0.653
Q8.IamDiligent	1.543	0.238	6.489	0.000	0.502	0.706
PER =~						
DM_Total	1.000				2.253	0.478
SP_Total	3.050	0.933	3.269	0.001	6.872	0.595
PRACTICE_str =~						
Trainng_cch_lg	1.000				0.159	0.686
Competition_lg	0.871	0.187	4.667	0.000	0.139	0.672

Regressions:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
PER ~						
Interest (c)	1.000	1.069	0.936	0.349	0.162	0.162
Persevrnc (c1)	0.788	0.955	0.825	0.409	0.114	0.114
PRACTICE_ (b)	4.859	2.048	2.373	0.018	0.344	0.344
PRACTICE_str ~						
Interest (a)	0.214	0.066	3.238	0.001	0.490	0.490
Persevrnc (a1)	-0.028	0.059	-0.481	0.631	-0.057	-0.057

Covariances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Interest ~~						
Perseverance	0.062	0.017	3.714	0.000	0.526	0.526

Finally, the last model had all the activities divided into two groups: Structured (Coach-led practice and Competition) and Unstructured (Self-led practice, Play with peers, and Indirect involvement). The results of the third model are presented in Table SM3 for the model with CI and PE (Model 3, Figure 4).

Table SM3. Model 3 – Practice represented as Structured (Coach-led (group) practice and Competition) and Unstructured practice (Self-led practice, Peer play, and Indirect involvement) with CI and PE.

Latent Variables:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Interest =~						
Q1.NwIdsDsMFPO	1.000				0.350	0.414
Q3.IHvBOAPSTLI	1.311	0.280	4.682	0.000	0.459	0.444
Q5.IOfSGBLCPDO	1.308	0.293	4.466	0.000	0.457	0.448
Q6.IhvdfMIPLFM	1.809	0.376	4.808	0.000	0.633	0.590
Perseverance =~						
Q4.IamHardWrkr	1.000				0.324	0.489
Q7.IFnshWhtvrB	1.567	0.259	6.055	0.000	0.508	0.653
Q8.IamDiligent	1.549	0.238	6.497	0.000	0.502	0.707
PER =~						
DM_Total	1.000				2.262	0.480
SP_Total	3.027	0.915	3.307	0.001	6.847	0.593
PRACTICE_str =~						
Competition_lg	1.000				0.134	0.650
Trainng_cch_lg	1.231	0.174	7.065	0.000	0.165	0.710
PRACTICE_unstr =~						
Training_sl_lg	1.000				0.312	0.748
Play_log	0.809	0.090	8.967	0.000	0.252	0.659
Indirect_log	0.696	0.091	7.612	0.000	0.217	0.545

Regressions:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
PER ~						
Interest (c)	1.112	1.112	1.000	0.317	0.172	0.172
Persevrnc (c1)	0.816	0.957	0.852	0.394	0.117	0.117
PRACTICE_ (b)	6.474	2.983	2.170	0.030	0.383	0.383
PRACTICE_ (b1)	-0.493	1.022	-0.482	0.630	-0.068	-0.068
PRACTICE_str ~						
Interest (a)	0.179	0.058	3.100	0.002	0.467	0.467
Persevrnc (a2)	-0.020	0.049	-0.408	0.683	-0.049	-0.049
PRACTICE_unstr ~						
Interest (a1)	0.367	0.122	3.006	0.003	0.412	0.412
Persevrnc (a3)	0.009	0.103	0.091	0.928	0.010	0.010

Covariances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
.PRACTICE_str ~~						
.PRACTICE_unstr	0.018	0.004	4.635	0.000	0.522	0.522
Interest ~~						
Perseverance	0.059	0.016	3.629	0.000	0.521	0.521

3) Cross-validation

We divided the dataset into two subsets, the training and test (validate) subsets (60:40 ratio). We then fitted the three models on the training dataset. The models are then validated on the test subset by fixing the parameters and specifying the starting values using the estimates from the training subset. We use Root Mean Squared Error (RMSE) as the main indicator the predictive power of the models, that is how the estimates from the training subset fit to the new test subset. RMSE measures the average prediction error made by the model in predicting the outcome for a model (in other words, the average difference between the observed known outcome values and the values predicted by the model – the lower the RMSE, the better the model). In all three instances, the RMSE values indicated excellent predictive fits (.051, .052., .051 for Model 1, Model 2, and Model 3, respectively, with none of the upper levels of the 95% CI reaching .08 – see Online Supplementary Material at the OSF).

4) Main models with grit as a single factor

Coach-led practice indeed mediates the influence of Grit on Perceptual-Cognitive Ability (Model 1A, Figure SM3). Grit is a significant predictor of (Coach-led) Practice (standardized beta, ß = .33; see the table below for raw estimates), which in turn directly determines Perceptual-Cognitive Ability (ß = .22). The results of the formal mediation analysis (Hayes, 2017) indicate that the indirect effect of grit on perceptual-cognitive ability (ß = .07) is not quite significant (p = .061). The SEM model shows that grit continues to exert considerable influence on perceptual-cognitive ability beyond the influence of (Coach-led) practice. The direct effect of grit on skill (ß = .36) just failed to reach the significance level (p = .051). However, when one considers both the direct (.36) and indirect effect (.07), the total effect of grit on skill is considerable (ß = .44) and significant (p = .028). Overall, a change of a standard deviation in the (standardized) grit score leads to a change of almost a half of standard deviation in the (standardized) perceptual-cognitive ability score (more precisely, .44).

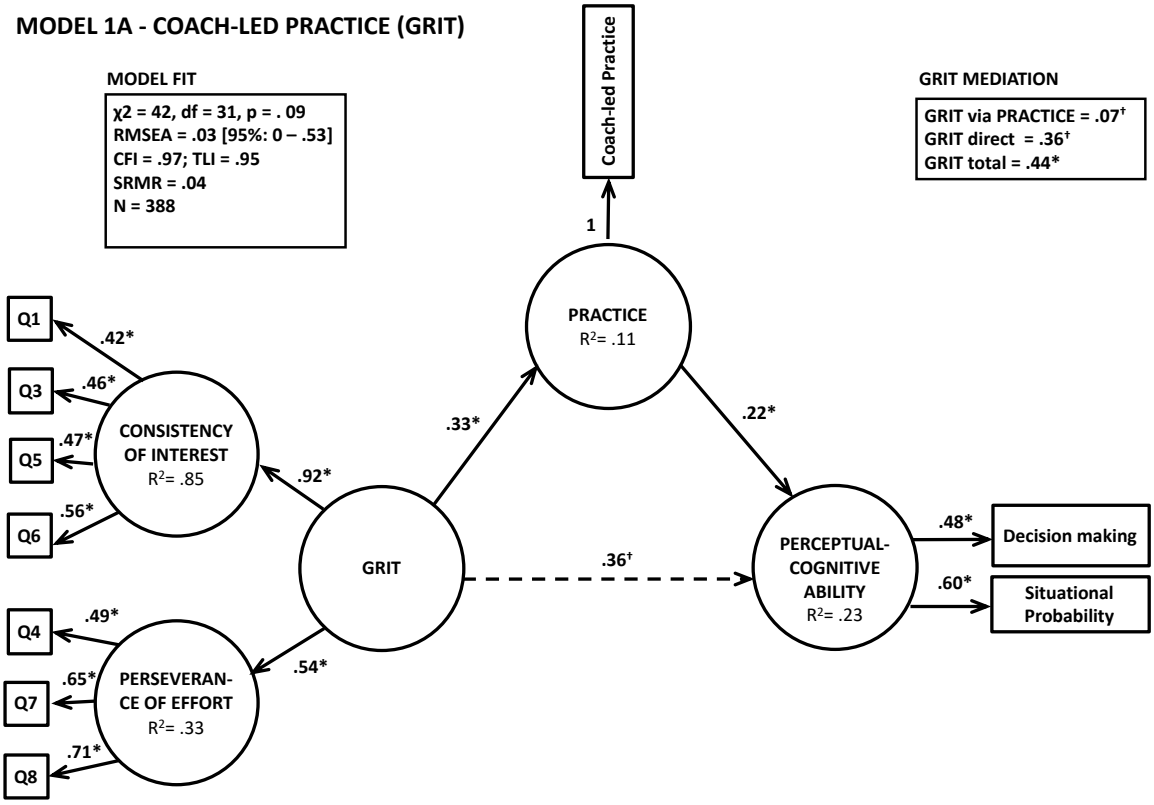

Figure SM3. SEM model for Practice defined as Coach-led practice and grit (Model 1A). The interplay between Practice and Grit (the predictors) and their influence on Perceptual-Cognitive Ability (dependent variable). Dotted lines indicate non-significant relations, dashed lines borderline significant ones, while full lines indicate significant relations. The numbers on the line are standardized SEM model coefficients. The indirect influence of Grit on Perceptual-Cognitive Ability through Practice is formally tested in a mediation model (upper right box). Model fit indices are presented in the upper left box. *$p < .05$, †$p < .06$.

Table SM4 provides the coefficients with SE for the model which features Coach-led (team) practice activities.

Table SM4. Model 1A – Practice represented as Coach-led (group) practice with Grit.

```
Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  Interest =~
    Q1.NwIdsDsMFPO    1.000                               0.359    0.425
    Q3.IHvBOAPSTLI    1.335    0.286    4.668    0.000    0.479    0.464
    Q5.IOfSGBLCPDO    1.328    0.300    4.431    0.000    0.477    0.466
    Q6.IhvdfMIPLFM    1.683    0.354    4.747    0.000    0.604    0.563
  Perseverance =~
    Q4.IamHardWrkr    1.000                               0.328    0.494
    Q7.IFnshWhtvrB    1.549    0.256    6.060    0.000    0.508    0.652
    Q8.IamDiligent    1.532    0.236    6.494    0.000    0.503    0.707
  Grit =~
    Interest          1.000                               0.924    0.924
    Perseverance      0.567    0.219    2.585    0.010    0.574    0.574
  PER =~
    DM_Total          1.000                               2.249    0.477
    SP_Total          3.090    0.980    3.153    0.002    6.950    0.600
  PRACTICE_str =~
    Trainng_cch_lg    1.000                               0.232    1.000

Regressions:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  PER ~
    Grit       (c)    2.477    1.270    1.951    0.051    0.365    0.365
    PRACTICE_s (b)    2.115    1.009    2.096    0.036    0.218    0.218
  PRACTICE_str ~
    Grit       (a)    0.228    0.084    2.706    0.007    0.326    0.326
```

We extended our initial model by adding Competition, another structured practice, to the latent construct of Practice (Figure SM4). The results of Model 2A were like the previous model: grit influenced practice (*ß* = .44), which then influenced skill (*ß* = .33), whereas grit explained skill beyond and above practice too (*ß* = .25). The actual mediation (*ß* = .15) was significant (*p* = .048), unlike the direct effect (*ß* = .25; *p* = .15). The overall influence of grit on skill, directly and indirectly, was considerable (*ß* = .40) and significant (*p* = .04).

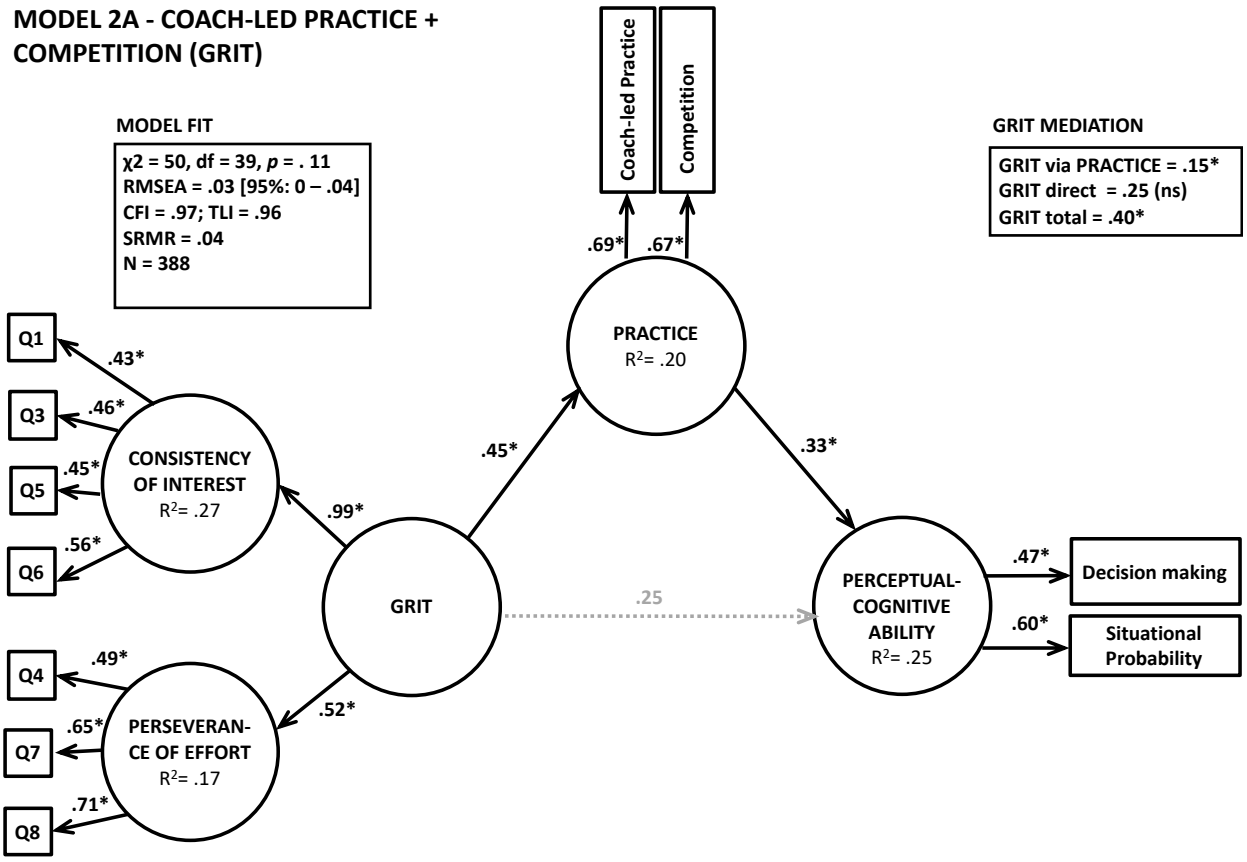

Figure SM4. SEM model for Practice defined as Coach-led practice + Competition and Grit (Model 2A). The interplay between Practice (Coach-led practice and Competition) and Grit (the predictors) and their influence on Perceptual-Cognitive Ability (dependent variable). Dotted lines indicate non-significant relations, dashed lines borderline significant ones, while full lines indicate significant relations. The numbers on the line are standardized SEM model coefficients. The indirect influence of Grit on Perceptual-Cognitive Ability through Practice is formally tested in a mediation model (upper right box). Model fit indices are presented in the upper left box. $^{*}p < .05$, $^{\dagger}p < .06$.

The second model, which was used using the same parameters as the first, added another structured practice activity, Competition, to Model 1. The results of the second model can be found in Table SM5.

Table SM5. Model 2A – Practice represented as Coach-led (group) practice + Competition with Grit.

Latent Variables:

		Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Interest =~							
Q1.NwIdsDsMFPO		1.000				0.367	0.434
Q3.IHvBOAPSTLI		1.308	0.274	4.780	0.000	0.480	0.464
Q5.IOfSGBLCPDO		1.252	0.281	4.458	0.000	0.459	0.450
Q6.IhvdfMIPLFM		1.639	0.337	4.867	0.000	0.601	0.560
Perseverance =~							
Q4.IamHardWrkr		1.000				0.325	0.490
Q7.IFnshWhtvrB		1.565	0.259	6.032	0.000	0.509	0.654
Q8.IamDiligent		1.541	0.238	6.486	0.000	0.501	0.705
Grit =~							
Interest		1.000				1.005	1.005
Perseverance		0.462	0.179	2.584	0.010	0.524	0.524
PER =~							
DM_Total		1.000				2.229	0.473
SP_Total		3.115	0.968	3.219	0.001	6.943	0.601
PRACTICE_str =~							
Trainng_cch_lg		1.000				0.161	0.693
Competition_lg		0.854	0.183	4.671	0.000	0.137	0.666

Regressions:

		Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
PER ~							
Grit	(c)	1.524	1.062	1.435	0.151	0.252	0.252
PRACTICE_s	(b)	4.558	2.003	2.276	0.023	0.329	0.329
PRACTICE_str ~							
Grit	(a)	0.195	0.074	2.625	0.009	0.446	0.446

Finally, the last model included the unstructured practice activities (self-led practice, play with peers, and indirect activities) in addition to the structured practice activities. Model 3A had two latent practice constructs which were predicted by grit, and which predicted perceptual-cognitive ability (Figure SM5).

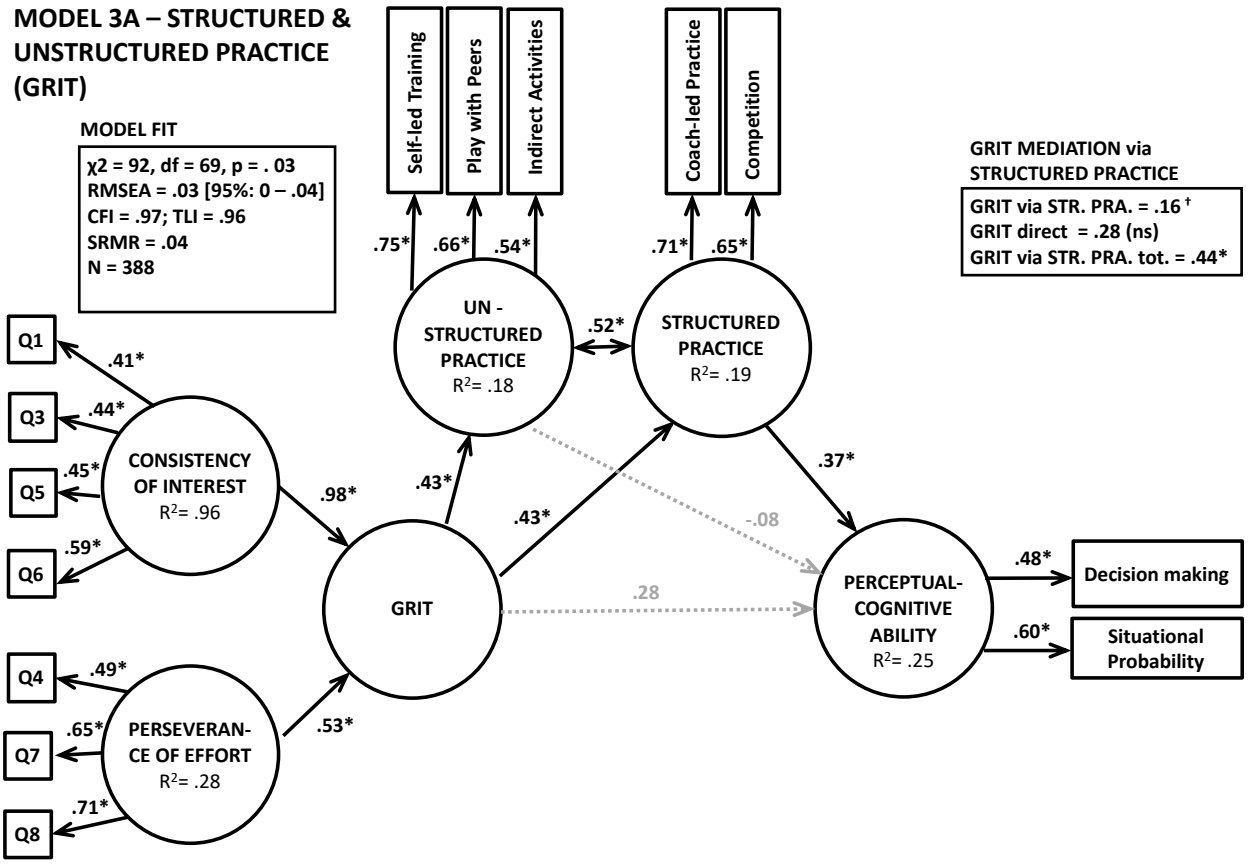

Figure SM5. SEM model for Practice defined as Coach-led practice + Competition and Grit (Model 3A). The interplay between Structured (Coach-led practice and Competition) and unstructured Practice (Self-led training, Play with peers, and Indirect activities), and Grit (the predictors) and their influence on Perceptual-Cognitive Ability (dependent variable). Dotted lines indicate non-significant relations, dashed lines borderline significant ones, while full lines indicate significant relations. The numbers on the line are standardized SEM model coefficients. The indirect influence of Grit on Perceptual-Cognitive Ability through Structured Practice is formally tested in a mediation model (upper right box; mediation through Unstructured Practice not shown as it is negligible and not significant). Model fit indices are presented in the upper left box. $^{*}p < .05$, $^{\dagger}p < .06$.

Grit was a positive and significant predictor of both structured (ß = .43) and unstructured (ß = .43) practice activities. Only structured activities, however, were significantly predictive of skill level (ß = .37). Unstructured activities had essentially no relation to perceptual-cognitive abilities (ß = -.06). The mediation of grit's influence on skill through structured practice was considerable (ß = .16) but not quite significant (p = .066). The same was the case with the direct influence of grit on skill (ß = .28), which was not significant (p = .12). The overall grit effect on skill was, however, large (ß = .44) and significant (p = .037).

The results of the third model are presented in Table SM6 for the model with girt.

Table SM6. Model 3A – Practice represented as Structured (Coach-led (group) practice and Competition) and Unstructured practice (Self-led practice, Peer play, and Indirect involvement) with Grit.

Latent Variables:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
Interest =~						
Q1.NwIdsDsMFPO	1.000				0.350	0.415
Q3.IHvBOAPSTLI	1.303	0.278	4.677	0.000	0.456	0.442
Q5.IOfSGBLCPDO	1.308	0.292	4.482	0.000	0.458	0.449
Q6.IhvdfMIPLFM	1.808	0.374	4.832	0.000	0.633	0.591
Perseverance =~						
Q4.IamHardWrkr	1.000				0.324	0.489
Q7.IFnshWhtvrB	1.566	0.259	6.053	0.000	0.508	0.653
Q8.IamDiligent	1.546	0.238	6.493	0.000	0.502	0.707
Grit =~						
Interest	1.000				0.978	0.978
Perseverance	0.505	0.172	2.933	0.003	0.533	0.533
PER =~						
DM_Total	1.000				2.238	0.475
SP_Total	3.088	0.946	3.264	0.001	6.913	0.598
PRACTICE_str =~						
Competition_lg	1.000				0.133	0.647
Trainng_cch_lg	1.243	0.176	7.056	0.000	0.166	0.714
PRACTICE_unstr =~						
Training_sl_lg	1.000				0.312	0.747
Play_log	0.809	0.090	8.983	0.000	0.252	0.659
Indirect_log	0.696	0.091	7.625	0.000	0.217	0.545

Regressions:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
PER ~						
Grit (c)	1.798	1.153	1.560	0.119	0.275	0.275
PRACTICE_ (b)	6.176	2.922	2.114	0.035	0.368	0.368
PRACTICE_ (b1)	-0.563	1.033	-0.545	0.586	-0.078	-0.078
PRACTICE_str ~						
Grit (a)	0.170	0.057	2.949	0.003	0.436	0.436
PRACTICE_unstr ~						
Grit (a1)	0.388	0.136	2.842	0.004	0.426	0.426

Covariances:

	Estimate	Std.Err	z-value	P(>|z|)	Std.lv	Std.all
.PRACTICE_str ~~						
.PRACTICE_unstr	0.018	0.004	4.417	0.000	0.519	0.519

5) Alternative Main Analysis – Path analysis with composites

The SEM analyses presented in the main text include the measurement error of the latent constructs. Here we demonstrate what happens when this measurement error is not taken into account as it is often the case in studies involving grit.

For the illustration, we used the first model with CI and PE (Model 1, Figure 2 in the main text). First, we constructed the CI and PE constructs by averaging the score on the items for these two constructs (excluding Q2 for PE). The performance/skill was constructed using the composite of the decision making and situational probability. Practice was the accumulated Coach-led training estimate. These constructs were then subjected to the same structural model as with the SEM. The difference is that this path analysis does not includes the measurement error associated with the constructs. In other words, it assumes that the constructs have been perfectly measured.

Figure SM6 depicts the standardized coefficients of this model. As can be seen, the CI coefficients are considerably higher than in the main SEM analysis (see Figure 3 in the main text). The SEs are also smaller, which in combination with larger coefficients led to the relations with CI to become statistically significant. Most importantly, the CI is now not only clearly better direct and indirect predictor of skill than PE, but also reliably so. The direct influence of CI (.42 vs. .07) is now significantly largen than that of PE, as is the mediation through practice (.14 vs. -.04), as well as the total effect on skill (.56 vs. .03).

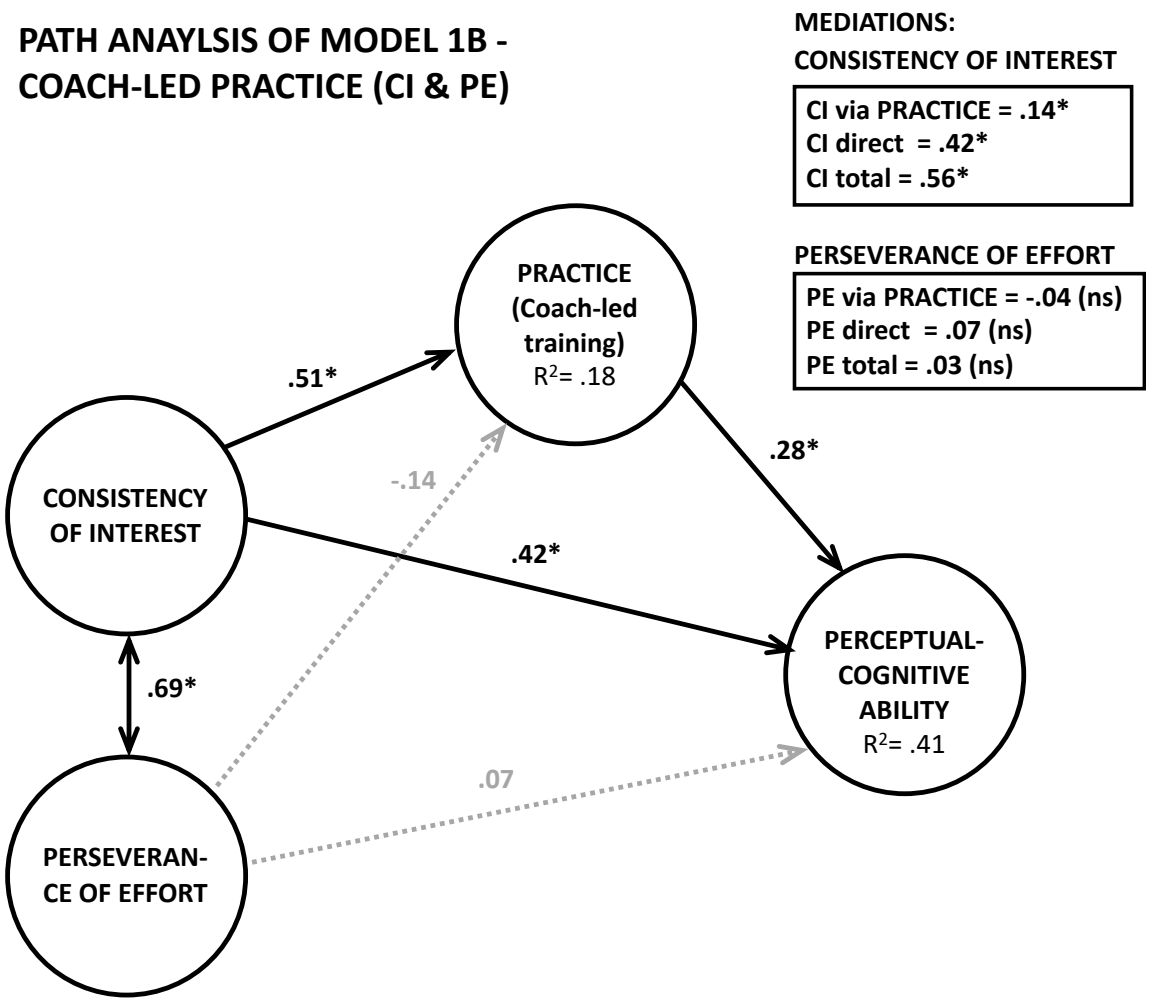

Figure SM6. Path analysis on composite score for Model 1B (Coach-led training with CI and PE). The analysis does not include measurement error of the individual manifest variable as the SEM analysis in the main text (see Figure 3). Consequently, the CI coefficient and their SEs are considerably larger, which leads to significant relations with other constructs as well as differences to PE.

SM References

Merkle, E. C., & Rosseel, Y. (2018). blavaan: Bayesian Structural Equation Models via Parameter Expansion. *Journal of Statistical Software*, *85*(1), 1–30. https://doi.org/10.18637/jss.v085.i04

Rosseel, Y. (2012). Lavaan: An R package for structural equation modeling and more. Version 0.5–12 (BETA). *Journal of Statistical Software*, *48*(2), 1–36.