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Superiority of External Attentional Focus for Motor Performance and Learning: Systematic Reviews and Meta-Analyses

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Considerable literature on the role of attentional focus in motor performance and learning has accumulated for over two decades. We report the results of comprehensive meta-analyses that address the impact of an external focus (EF, on intended movement effects) versus internal focus (IF, on movements of body parts) of attention on the performance and learning of motor skills. Values of effect sizes (ES) from 73 studies with 1,824 participants and 40 studies with 1,274 participants were used for examining the effects of EF versus IF on behavioral outcomes of motor performance and learning (separately for retention and transfer phases) respectively. The EF condition was more effective than the IF condition for performance, Hedges' g value = 0.264 (95% CI [0.217, 0.310]), retention learning, Hedges' g value = 0.583 (95% CI [0.425, 0.741]), and transfer learning, Hedges' g value = 0.584 (95% CI [0.325, 0.842]). Multivariable metaregression analyses on behavioral measures further indicated that neither age group, health status, or skill level, nor their two-way interactions, moderated the ES differences between EF and IF in performance, retention, and transfer models (all $p > .100$). A secondary analysis on 12 studies with 216 participants that examined the effects of EF versus IF on electromyographic outcomes of motor performance also indicated that EF was associated with more efficient neuromuscular processing, Hedges' g value = 0.833 (95% CI [0.453, 1.213]). From nine studies with 272 participants, performance measured by behavioral outcomes was found to be more effective when a more distal, rather than proximal, EF was used, Hedges' g value = 0.224 (95% CI [0.019, 0.429]). Overall, the meta-analytic results are consistent with prior narrative reviews and indicate that an external focus is superior to an internal focus whether considering tests of motor performance or learning, and regardless of age, health condition, and level of skill expertise.

Public Significance Statement

Meta-analyses show that the use of external focus, by directing attention to intended movement effects, provides advantages for performing and learning motor skills. These beneficial effects are present whether the individual is a child or adult, has a clinical condition or not, and is considered to be a novice, experienced, or an expert at the motor skill.

Keywords: attentional focus, skill execution, skill acquisition, movement effects, meta-analytic review

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Does it matter whether a young soccer player, an elite musician, or someone recovering from a stroke focuses on how to move body parts or their intended goal when they move? This seemingly simple question captures a central scientific and applied issue—the impact of attentional focus—in the performance and learning of motor skills studied over two decades. Achieving a skill level that is characterized by movement accuracy and consistency, automaticity, and fluent, economical movements requires considerable practice. The understanding of how various factors influence motor performance and learning is essential for the development of optimal training methods. The implementation of valuable practice methods can effectively speed up the learning process, resulting in higher skill levels being achieved sooner and with possible reduced training costs (e.g., physical rehabilitation, medical

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education). Optimized training protocols may also enhance performers' safety (e.g., patients at risk of falling, military personnel, athletes in high-risk sports) as well as their ultimate performance (e.g., athletes competing internationally).

Research related to variables that influence the learning of motor skills has been concerned with a variety of practice variables (e.g., variable vs. constant practice, random vs. blocked practice, feedback frequency, movement observation, learner-controlled practice). One factor that has sparked the interest of many researchers over the past two decades is the performer's focus of attention that is induced by instructions or feedback. As numerous studies have shown, a small (i.e., one or two-word) difference in the wording of instructions can lead to distinct differences in performance or learning outcomes (for a review, see Wulf, 2013). Specifically, this line of research has demonstrated that instructions promoting an external attentional focus (EF), or concentration on the intended movement effect (e.g., motion of an implement, hitting a target, producing a "spiral" throw) result in superior performance and learning than does an internal focus (IF), or concentration on body movements (see Wulf, 2013).[1] Wulf et al. (1998) first demonstrated learning benefits of instructions to adopt an EF. In their study, instructions to focus attention (externally) on the wheels of a ski simulator (Experiment 1) or markers on a balance platform (Experiment 2) resulted in enhanced task learning compared with instructions to focus (internally) on the feet. Thus, a small difference in the instructions (e.g., "the markers" vs. "your feet") had significantly different effects on learning outcomes. Given that the feet were directly above the wheels or behind the markers, respectively, the impact of this minor change in attentional focus on the coordination of whole-body movements and resulting movement effectiveness surprised many. Since those initial findings, many experimental studies have followed. Much of this research has previously been reviewed in a comprehensive narrative (e.g., Lohse et al., 2012; Wulf, 2007a, 2007b, 2013; Wulf & Lewthwaite, 2010, 2016; Wulf & Prinz, 2001) or a more focused manner (e.g., Kim et al., 2017; Marchant, 2011; Park et al., 2015; Ziv & Lidor, 2015). Therefore, rather than providing another literature review, the main goal of the present study was to undertake a comprehensive meta-analytic review to provide quantitative dimensions to the findings.

The relative effectiveness of external versus internal foci of attention has been examined with respect to multiple dimensions of motor performance, including the effectiveness of movements and their outcomes, the efficiency with which movements are performed, and automaticity in the control of movements. Movement effectiveness is reflected, for example, in the accuracy with which a target is hit in tasks involving throwing or hitting objects (e.g., Bell & Hardy, 2009; Lohse et al., 2010), deviations from a balanced position or time in balance (for a review, see Kim et al., 2017), quality of movement form (e.g., Abdollahipour et al., 2015; An et al., 2013), or musical performance (e.g., Mornell & Wulf, 2019) as determined by kinematic measures or expert ratings, and many others. Movement efficiency has been operationalized as reduced oxygen consumption for a given task (e.g., Hill et al., 2017; Schücker et al., 2009), reduced muscular activity and cocontraction (e.g., Lohse et al., 2011; Vance et al., 2004), greater movement fluidity (e.g., Kal et al., 2013), or greater sustainability of motor activities such as weightlifting (Marchant et al., 2011; Nadzalan et al., 2015). Finally, some studies examined the degree of automaticity in movement control when individuals were instructed to adopt an EF or IF. Automaticity has been measured by dual-task performances, mean power frequency of movement adjustments, sample entropy, or jerk (e.g., Kal et al., 2013; Wulf et al., 2001). Effects of attentional focus are also seen in the neuromuscular and neural underpinnings of movement effectiveness, efficiency, and automaticity, including muscular activation or electromyographic (EMG) activity (e.g., Marchant, Greig, & Scott, 2009; Vance et al., 2004), cortical activity (e.g., Kuhn et al., 2017), and corticospinal modulation (e.g., Kuhn et al., 2018).

While the conclusions drawn from individual studies and narrative reviews appear to be consistent in showing benefits of an EF relative to an IF, a referendum on the quantitative impacts of the attentional focus effect is outstanding. We therefore conducted a series of meta-analyses to evaluate the strength and breadth of effects of an EF versus IF on motor performance as well as learning, as measured by retention or transfer tests. Moreover, we examined potential moderator variables, including age group, health status, and skill level (see following sections).

It should be noted that many studies of attentional focus included control conditions without specific focus instructions. In most of those studies, control conditions resulted in similar performance or learning as IF conditions, with both being less effective than EF conditions (for a review, see Wulf, 2013). Control conditions are not included in the present meta-analyses, however, for several reasons. First, thoughts may be stable, fleeting, random, absent, or directed at cues other than the external-internal focus of interest in conditions for which no explicit instruction or only a general instruction is given. Importantly, most studies did not attempt to assess participants' thoughts after specific instruction or the absence of instruction. Those few studies that did examine participants' reports of the content of their thoughts or attentional focus via postperformance questionnaire (e.g., Becker & Smith, 2013; Land et al., 2014) or interview

[1] The present meta-analyses do not include studies concerned with other types of attentional focus such as associative (i.e., focusing on bodily sensation such as breathing mechanics) versus dissociative (i.e., blocking out sensations resulting from physical effort) (Morgan, 1978; Schücker & Parrington, 2019; Weinberg et al., 1984). Those are often found in the literature of endurance or cyclic-type sports such as running, cycling, or rowing. While an associative focus and an internal focus of attention share an ostensible emphasis on intrinsic physiologic sensations, they do so in different ways. The former tunes to ongoing monitoring of physiological output, while the latter is more directed to movement execution of upcoming action. More importantly, dissociative strategies favor distraction from the ongoing endurance task (i.e., not on the task), while an external focus of attention concerns concentration directed to the intended movement effect (i.e., distinctly task-focused). See, for example, Schücker and Parrington (2019) for experimental comparisons of these approaches. Our meta-analyses also do not include studies related to skill-focused versus non-skill focused attention (e.g., Beilock et al., 2002; Gray, 2004). A skill focus has been operationalized differently in different studies and can induce either an internal focus (e.g., foot in soccer dribbling, Beilock et al., 2002) or external focus (e.g., motion of baseball bat, Gray, 2004). All studies in the internal and external focus of attention literature, would, by definition, be focused on some aspect of skill execution.

(e.g., Abdollahipour et al., 2014; Chow et al., 2014; Ille et al., 2013) suggest that participants' foci tended to be internal (e.g., Pascua et al., 2015) or a mixture of internal and external (e.g., Christina & Alpenfels, 2014; Mornell & Wulf, 2019) when no focus direction was given. Second, examination of control versus specific attentional focus conditions might be seen to address a separate, albeit interesting question, namely, what attentional focus performers or learners spontaneously adopt when not specifically prompted with instructions. One might expect some change in the content of this self-instruction (i.e., a cohort effect) as findings from decades of attentional focus research begin to affect the instructional practices of teachers, coaches, clinicians, and other practitioners. Therefore, we contrast only EF and IF conditions in our meta-analyses.

Performance Versus Learning

Initial attentional focus investigations were concerned with effects of external versus internal foci on motor *learning* (e.g., Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., 1999; Wulf et al., 2001). Learning reflects a relatively permanent change in the capability to perform a skill (for a conceptual explanation, see Schmidt et al., 2019) and is typically measured by delayed retention or transfer tests during which no focus instructions or reminders are given. In addition to learning differences seen on retention or transfer tests in early studies (e.g., Wulf et al., 1998, Experiment 1; Wulf et al., 1999; Totsika & Wulf, 2003), it appeared that the instructed attentional foci (EF, IF) affected practice performance, with group differences sometimes occurring almost immediately. Subsequent studies therefore began to examine effects of attentional focus on motor performance, using within-participant designs in which all participants performed under all conditions, typically in a counterbalanced order (e.g., Landers et al., 2005; McNevin & Wulf, 2002; Zachry et al., 2005). Those studies generally confirmed that an EF has the potential to produce immediate performance advantages compared with an IF.

Given the distinction between immediate performance, and sustained and more generalizable impacts on learning (Schmidt et al., 2019), as well as the availability of relatively large numbers of studies that addressed either performance (typically using within-participant designs) or learning (typically using between-participants designs), we performed separate meta-analyses to calculate effect sizes for each of these two types of studies. Furthermore, learning studies use retention and/or transfer tests, both of which are typically conducted after a delay of at least 24 hr, and in which all groups perform under identical conditions (no focus instructions). While retention tests involve the same task that was practiced, transfer tests include a new variation of the task (e.g., a different target distance) to determine the generalizability of learning to novel conditions (see Schmidt et al., 2019). Separate meta-analyses were conducted to determine effect sizes for each of these two tests of learning.

Potential Moderators

Are there moderating influences on the effects of an EF versus IF? We considered several potential moderator variables, including the performers' age group, health status, and skill level.

Age Group

While most studies have been conducted with young adults (e.g., college students), several studies included children or older adults as participants. Presumed differences in information processing capabilities or ability to maintain a certain attentional focus, relative to young adults, were often used as the rationale for the inclusion of different age groups. Children were asked to perform motor tasks such as riding a Pedalo (Flôres et al., 2015), throwing balls at a target (e.g., Saemi et al., 2013), or playing tennis (Tsetseli et al., 2016). Learning benefits of an EF were found in several studies (e.g., Hadler et al., 2014; Tsetseli et al., 2016), while other researchers (Agar et al., 2016; Emanuel et al., 2008) found no learning differences between groups of children who received EF or IF instructions. Based on null effects, some of those authors have argued that children may not benefit from an EF, or even that an IF might be more effective. A few studies examined effects of EF and IF in older adults. For example, participants in their seventies performed tracking (McNevin et al., 2013) or balance tasks (Mückel & Mehrholz, 2014; Wulf et al., 2009). For older adults, results have been mixed, with some studies showing no differences in performance between EF and IF conditions (e.g., Yogev-Seligmann et al., 2017) and other studies showing EF benefits (e.g., Porter & Anton, 2011). Age group was therefore included as a moderator variable in our analyses: children (4−17 years), adults (18−59 years), and older adults (60 years and older).

Health Status

An individual's attentional focus has been shown to not only influence performance and learning in healthy people but also in other, challenged populations. For instance, researchers have examined motor performance as a function of EF versus IF in adults with injuries (Laufer et al., 2007; Rotem-Lehrer & Laufer, 2007) or motor impairments caused by Parkinson's disease (Beck et al., 2018; Landers et al., 2005; Wulf et al., 2009), stroke (Fasoli et al., 2002), or multiple sclerosis (Shafizadeh, Platt, & Mohammadi, 2013). Other studies have included children with intellectual disabilities (Chiviacowsky et al., 2013), attention deficit hyperactivity disorder (Saemi et al., 2013), or autism (e.g., Tse, 2017). Under the assumption that the ability to control movements intentionally or automatically may be compromised by some clinical conditions, such as Parkinson's disease (e.g., Beck et al., 2018; Cunnington et al., 1999; Oliveira et al., 1997), we included health status as a moderator variable. Within this analysis, those deemed "without clinical condition" for our purposes came from one of two categories: Research participants who were assumed to be healthy in nonclinical studies or who did not have the clinical condition being studied (e.g., healthy controls) in clinical studies, versus research participants with a clinical condition that was being studied. Conditions of the research participants in the "with clinical condition" category included a variety of diseases, disorders, illnesses, injuries, and syndromes that all required medical treatment, but do not fall into a single classification (Tresker, 2020).

Skill Level

While most attentional focus studies used nonexperts or novices as participants, a number of studies included experienced performers, such as golfers (Christina & Alpenfels, 2014), boxers (Halperin et al., 2017, Experiment 2), or volleyball players (Wulf et al., 2002). Several studies also included expert performers such as boxers (Halperin et al., 2017, Experiment 1), marksmen (Hosseiny et al., 2014), balance acrobats (Wulf, 2008), or golfers (Bell & Hardy, 2009; Wulf & Su, 2007). Some authors have argued that novices should benefit from an IF (Peh et al., 2011), while others have claimed that expert performers need to focus on their body movements (i.e., use IF) for continued improvement (e.g., Toner et al., 2016; Toner & Moran, 2015). These assertions have been more conceptual than empirically derived, but we included level of skill as a moderator variable to determine whether effect sizes would differ depending on the performer's skill level.

Secondary Analyses

Neuromuscular Efficiency

In addition to behavioral outcome measures indicative of motor performance quantitatively (e.g., deviation from a target, time in balance) or qualitatively (e.g., movement form, musical sound quality from played instruments), studies have begun to consider potential neuromotor and neurocognitive mediators or other neurophysiological mechanisms of these behavioral effects. We describe several studies of brain-related neurophysiological activity associated with different attentional foci, but this area of the literature is nascent and not yet amenable to meta-analytic evaluation. A body of work, nevertheless, has assessed muscular (EMG) activity under EF and IF conditions for tasks involving maximal or submaximal force production (e.g., Greig & Marchant, 2014; Halperin, Hughes et al., 2016; Lohse & Sherwood, 2012; Vance et al., 2004), basketball free-throw shooting (Zachry et al., 2005), or dart throwing (Lohse et al., 2010). We examined EMG activity only in the context of significant behavioral effects of attentional focus. Further, we assume that EMG activity may differ as a function of several mechanisms, including muscle and motor unit recruitment, as well as altered movement form providing biomechanical advantage or disadvantage. EMG activity, in relation to force output, is a measure of the neuromuscular efficiency with which movements are performed in a particular motor task (see, e.g., Campos et al., 2021; Patsika et al., 2011). If the same (or a better) outcome is achieved with less muscular activity, whether as a result of a different movement pattern or with the same movement form achieved more efficiently, movements may be considered more efficient, as lower EMG activity reflects a more economical recruitment of muscle fibers. We conducted a separate meta-analysis for motor performance studies examining EMG activity as a function of attentional focus.

Relative Distance of the External Focus

Are some external foci more effective than others? Some evidence suggests that external foci "located" at greater distances from the performer's body (i.e., distal foci)—perhaps because they are more easily distinguishable from body movements—are more effective than foci in close proximity to the performer's body (for a review, see Wulf, 2013). McNevin et al. (2003) first demonstrated that increasing the distance of the EF from the body increased the advantage of the EF. Concentrating on the movement of markers on a balance platform that were farther away from the feet (distal EF) resulted in more effective balance learning than did concentrating on markers close to the feet (proximal EF) or the feet themselves (IF). The "distance effect" has been replicated in other studies (e.g., Bell & Hardy, 2009; McKay & Wulf, 2012; Porter et al., 2012). Bell and Hardy's study, for instance, demonstrated greater accuracy in hitting golf balls when the focus was on the ball trajectory and landing point (distal EF) compared with the club (proximal EF). McKay and Wulf (2012) found that accuracy in dart throwing was improved with a focus on the bullseye (distal EF) as opposed to the flight of the dart (proximal EF). Therefore, in a separate meta-analysis, we included studies that specifically compared the effect of a distal versus proximal EF.

The Present Study

To date, the evidence synthesis of attentional focus effects has largely focused on the use of narrative (e.g., Lohse et al., 2012; Wulf, 2007a, 2007b, 2013; Wulf & Lewthwaite, 2010, 2016; Wulf & Prinz, 2001) or systematic (e.g., Neumann, 2019; Piccoli et al., 2018; Sturmberg et al., 2013) reviews without data aggregation, or meta-analyses limited to the analysis of single categories of motor tasks in either motor performance studies (Makaruk et al., 2020) or motor learning studies (Kim et al., 2017). We aimed to not only systematically find and select research studies from extant scientific literature comprised of experimental studies that compared the effects of different types of attentional focus using various outcome measures, but also comprehensively synthesize available empirical data, which have accumulated for over two decades, from this large pool of research studies across various design, sample, and task characteristics. For the purpose of providing an updated, extensive overview, we conducted meta-analyses to assess the strength and breadth of the effect of an external relative to an internal focus of attention on both motor performance and learning (retention, transfer). We also included several potential moderator variables (i.e., age, health status, and skill level) in our analyses. Moreover in secondary meta-analyses, we examined effects on neuromuscular efficiency (i.e., EMG activity in relation to force output for a given motor task) of an EF versus an IF, as well as the strength of the distance effect (i.e., distal vs. proximal foci) in using an EF.

Method

The meta-analyses were conducted according to the general guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2009).

Literature Search

A literature search for potentially eligible studies, which examined attentional focus effects on motor performance and learning, was conducted using the following electronic databases: APA PsycINFO, PubMed, SPORTDiscus, and Web of Science. The following general keywords and Boolean operators were used for the search: (attentional focus OR external focus OR focus of attention) AND (motor performance OR motor learning). In addition to electronic database searches, the reference lists of retrieved articles and one author's (GW) personal archive of research articles were manually reviewed to identify relevant research studies that may have been omitted by our choice of keywords used in the initial computerized search approach. During the coding phase (prior to statistical analysis), we further maintained a systematic lookout for newly published articles with relevant content through the receipt of email alerts from Google Scholar and ResearchGate. Finally, a single relevant article was also brought to our attention by its first author whom we contacted with a request for additional statistical data related to another of that author's studies on attentional focus. These search strategies collectively produced an additional 91 research articles.

Eligibility Criteria

To be included in these meta-analyses, studies needed to satisfy the following criteria: (a) published in the English language between February 1998 (i.e., time of publication of the first study comparing the effects of EF and IF: Wulf et al., 1998) and April 2019; (b) published in a peer-reviewed journal to provide some degree of quality assurance; (c) compared external and internal foci of attention, or at least two types of EF; (d) assessed the performance or learning of a motor skill; (e) used within-participant and between-participants designs for assessing motor performance and learning respectively; (f) provided sufficient statistical information for the calculation of ES and variance; and (g) used an experimental design. Studies that were observational in nature, used a qualitative design, only surveyed participants' future preference regarding attentional focus usage, or solicited retrospective reports of the use of various attentional foci in a preceding activity were excluded from this meta-analytic study.

Study Selection and Data Abstraction

Two authors (LC and TK) independently identified relevant studies and extracted all required data. Disagreements regarding the inclusion of studies and extraction of data were resolved by consensus and with the help of two other authors (RL and GW).

Prior to data extraction, a codebook was developed using Microsoft Excel, Version 2.16. General items coded included: age group (i.e., children: 4−17 years; adults: 18−59 years; older adults: ≥60 years), sex (i.e., female or male), health status (i.e., with or without clinical condition), type of clinical condition (if any), skill level (i.e., novice, experienced, or expert), type of measurement of the primary (and if any, intermediary) dependent variable, type of EMG measure (if any), type of test (i.e., performance, retention, or transfer), delay period for retention or transfer test, relative distance of the EF (i.e., distal or proximal EF) if more than one type of EF was used, and counterbalancing nature for within-participant designs or randomization nature for between-participants designs. Included studies examined a wide range of behavioral measures for assessing motor performance and/or learning outcomes, which can be broadly categorized as measurements of speed, accuracy, force, time, endurance, postural sway, consistency, error or deviation, distance, movement economy, movement form or pattern, and musical sound quality.[2] Studies that included EMG measures for the assessment of muscular activity were coded separately for an additional (secondary) analysis. For studies that used more than one behavioral measure to assess motor performance or learning, or its neuromuscular correlates, only a single dependent measure per independent subgroup for each type of outcome (behavioral or neuromuscular) that best addressed the primary research question of the study was selected for further analysis to avoid overcounting bias (Rosenthal, 1995; Senn, 2009). In most cases, the selection of the dependent variable was straightforward, either because only one outcome measure was used (e.g., da Silva et al., 2017; Freudenheim et al., 2010; Tse, 2017), the attentional focus instructions or feedback were designed to affect one variable (e.g., movement form) rather than another (e.g., accuracy; Wulf, Chiviacowsky, et al., 2010), or the authors identified a measure of primary interest (e.g., oxygen consumption rather than other spirometric measures; Schücker et al., 2009). Further, in several studies that included kinematic or kinetic measures, these were clearly used as a supplement to the analysis of the main performance measure such as maximum jump height (Wulf & Dufek, 2009), maximum jump distance (Makaruk et al., 2012), movement time in functional reaching (Fasoli et al., 2002), or carry distance of a golf ball (An et al., 2013). Occasionally, a dependent measure was chosen because it seemed to best represent task performance and was consistently mentioned first by the authors (e.g., step length rather than step length variability, step time, etc.; Beck et al., 2018). In the very few cases, in which two dependent measures appeared to be of equal importance, we arbitrarily selected one of them (Halperin et al., 2017; Raisbeck & Yamada, 2019).

Risk of Bias

We used the revised Cochrane risk-of-bias tool for randomized trials (RoB2; Higgins et al., 2019) to assess the potential for bias of each study. According to this assessment tool, risks of bias are classified as "low", "some concern", or "high risk". Our judgments yielded low risk of bias for most (75.5%) and moderate risk (representative of "some concern") for other studies (for details, see the Appendix). Risk of bias was considered moderate for those studies in which the measurement of the outcome (e.g., use of a stopwatch

[2] Dependent measures varied among studies, even for similar tasks or aspects of performance. For instance, in the case of balance tasks in which minimizing postural sway or maintaining a balanced position was the goal, various measures of balance performance were used, including time in balance as defined by a platform position within a certain bandwidth of deviation (e.g., Jackson & Holmes, 2011), the root-mean-square error of the deviation from a horizontal position (e.g., Wulf et al., 1998), or a stability index provided by an instrument (e.g., Biodex Stability System, Laufer et al., 2007). For tasks requiring hitting a target or producing a certain amount of force, measures of accuracy were used such as the deviation from the center of a bullseye (e.g., radial error, Marchant, Carnegie, et al., 2018), a score for hitting a certain area around the target (e.g., Agar et al., 2016; Hadler et al., 2014), the percentage of successful trials (e.g., basketball shots, Maurer & Munzert, 2013), or deviation from a target force (e.g., Lohse et al., 2011). When the task goal involved maximum performance, such as maximum jump height (e.g., Abdollahipour et al., 2016) or distance (e.g., Wu et al., 2012), maximal force production (e.g., Halperin, Williams, et al., 2016), propelling an object as far as possible (e.g., An et al., 2013; Zarghami et al., 2012), or number of repetitions to failure (e.g., Marchant et al., 2011), performance was measured accordingly. In some case, somewhat more subjective measures derived from assessment instruments such as the Game Performance Assessment Instrument for tennis (Tsetseli et al., 2016), Berg Balance Scale (e.g., Landers et al., 2016), or blinded expert ratings to assess musical or gymnastics performance (Abdollahipour et al., 2015; Mornell & Wulf, 2019) were used. A complete list of dependent measures used in the present meta-analyses can be found in the Appendix.

for speed-related tasks, using a measuring tape for long jump, assignment of accuracy score for throwing tasks) could have been affected by the experimenter's knowledge of the attentional focus condition under which the participant performed. We further conducted subgroup analyses to assess whether studies with moderate risk of bias produce different effect sizes from studies with low risk of bias.

Estimation of Effect Sizes

The primary outcome for this meta-analytic study was the effect size (ES) under EF versus IF conditions calculated as corrected standardized mean difference (i.e., Hedges' *g*). Hedges' *g* values were calculated from means, standard deviations (as indicated or converted from standard errors), and sample sizes reported in the original studies (Borenstein et al., 2009). In the absence of this information, Hedges' *g* value was calculated from the *F* value or *t*-value (Lipsey & Wilson, 2001). For studies using a within-participant design, the pooled standard deviation was averaged across the two conditions for the calculation of the uncorrected standardized mean difference, and the variance of the uncorrected standardized mean difference value was calculated using an assumed coefficient value of .5 for correlation. Hedges' *g* values were analyzed separately for studies comparing the effects of EF versus IF on motor performance (using within-participant designs) or motor learning (using between-participants designs), as measured by retention and transfer tests. The secondary meta-analyses on EMG and distance effect used only studies with a within-participant design. For studies that implemented more than one EF condition, the EF condition containing an attentional cue that most closely matched the IF attentional cue was selected for comparison with the IF condition. Likewise, for studies that implemented more than one IF condition, the IF instruction or feedback that most closely matched that used in the EF condition was used. When a study reported information for independent subgroups belonging to different age group categories (children: 4−17 years; adults: 18−59 years; older adults: ≥60 years), different health status (healthy vs. with clinical condition), or different skill levels (novice, experienced, and expert), all possible values of Hedges' *g* were calculated for moderator variable analyses. Hedges' *g* value was coded in the direction in which a higher score reflected a better outcome, and a positive Hedges' *g* value indicated that EF was more effective than IF. For the studies in which both distal EF and proximal EF were used, the types of EF were coded. For this secondary analysis, the Hedges' *g* value compared distal versus proximal EF conditions such that a positive Hedges' *g* value indicated that a distal EF was more effective than a proximal EF. Hedges' *g* values of 0.2, 0.5, and 0.8 were interpreted as small, medium, and large, respectively (Cohen, 1988).

Pooling of Effect Sizes

Random-effects models (DerSimonian & Laird, 1986) using a restricted maximum likelihood method to estimate between-study variance were used to pool Hedges' *g* values according to the guidelines outlined by Borenstein et al. (2009), due to expected and tested heterogeneity. For studies with multiple independent subgroups that could not be separately classified into any of the stipulated three age groups, two health statuses, or three skill levels, a composite Hedges' *g* value per study was calculated to be used subsequently for the computation of the overall Hedges' *g* value for each analysis of interest. A 95% CI for each Hedges' *g* value, calculated from the variance of the Hedges' *g* value, was used to assess the statistical significance and precision of the estimated value of the Hedges' *g* value; any interval that did not contain a zero value warranted the rejection of the null hypothesis that the mean effect is zero (Borenstein et al., 2009). In total, five overall Hedges' *g* values were calculated. There were three overall Hedges' *g* values for the primary meta-analyses that compared the effects of EF with those of IF on motor behavioral measures, consisting of an overall Hedges' *g* value for motor performance in studies using a within-participant design, and for studies of learning, an overall Hedges' *g* value for the retention phase and a separate one for the transfer phase (both using a between-participants design). For the two secondary meta-analyses, both involved the use of studies with a within-participant design. One overall Hedges' *g* value compared EMG activity between EF and IF conditions while the other used an overall Hedges' *g* value comparing distal versus proximal EF. In this latter investigation of the distance effect of using EF, only motor performance effects could be analyzed because insufficient numbers of studies were available for meta-analytic examination of retention (four: Abdollahipour et al., 2014; McNevin et al., 2003; Shafizadeh et al., 2011; Wulf et al., 2000, Experiment 2) and transfer (two: Abdollahipour et al., 2014; Flôres et al., 2015) test results to determine motor learning effects. This was due to the consideration of the issues of Type I error rates and statistical power associated with any meta-analysis of a small number of studies, for which we adopted the use of a criterion requiring the availability of at least five effect sizes for quantitative synthesis (Jackson & Turner, 2017). Data analyses were conducted using the OpenMEE (Open Meta-analyst for Ecology and Evolution; Wallace et al., 2017) and R (R Core Team, 2018) programs.

Heterogeneity and Publication Bias

The presence of heterogeneity across included studies was examined using Cochran's *Q*-test, while the extent of observed heterogeneity in terms of the proportion of Hedges' *g* estimates due to differences among the included studies, rather than within-study sampling error, was assessed using the I^2 index (Borenstein et al., 2009). Additionally, we reported values of the τ^2 statistic (determined using the restricted maximum likelihood estimator) to facilitate the interpretative comparison of true between-study heterogeneity across different contexts beyond the current sample of included studies (Rücker et al., 2008). Statistical significance for the *Q*-statistic was set at $p \leq .100$. We interpreted I^2 indices of 25%, 50%, and 75% as representing low, moderate, and high degrees of heterogeneity between included studies on a relative scale (Higgins et al., 2003). As a general reference, a small index value of I^2 indicated that the reported Hedges' *g* value is comparable across studies included in the analysis of interest whereas a larger index value is indicative of substantial variation across them (Borenstein et al., 2017). To examine potential publication bias, the possible presence of small-study effects was assessed using visual inspection of funnel plots (Sedgwick & Marston, 2015) and Egger's regression test results (Egger et al., 1997). Furthermore, to eliminate the influence of extreme ES values on the meta-analytic results, a statistical outlier analysis was conducted to determine values of overall Hedges' g, Q, I^2, and τ^2 after the removal of individual ES both containing a Hedges' g value with a 95% CI that falls completely outside of the 95% CI of the overall Hedges' g value for the meta-analysis of interest (Viechtbauer & Cheung, 2010). Thereafter, for the sensitivity analysis excluding outliers, we adopted the nonstandard, selection-model approach of Mathur and VanderWeele (2020) that is based on inverse probability weighting and maximum likelihood estimation, and does not require the normal distribution of population effects, a large number ($\geq$ 10) of ES entries, and all ES entries to be independent of one another (i.e., contributed by separate studies). Instead of attempting to provide a bias-correction to the meta-analytic estimate of the observed overall ES, this approach was used primarily to provide an intuitive interpretation of how sensitive a given value of observed overall ES computed from each set of included studies (with outliers removed) was to publication bias by calculating the ratio of affirmative results (i.e., ES entries that have a statistically significant positive value based on a significance level of .050) to nonaffirmative results (i.e., ES entries that are statistically nonsignificant based on a significance level of .050, or have a zero or negative value) that could attenuate the meta-analytic ES to the null value. In general, a large ratio value would imply that the meta-analytic result is relatively robust to publication bias because a large number of studies in support of the hypothesis representing the observed effect would need to be published relative to studies not in support of the hypothesis in order to nullify the observed overall ES value. On the other hand, small ratio values would suggest that meta-analytic results are relatively sensitive to publication bias. For purposes of precision in our evaluation of publication bias, an empirical benchmark ratio value of 5 (rounded up from 4.84 as the 95th quantile of the distribution of true ratio values from 17 meta-analytic studies published in three top experimental psychology journals; for details, see Mathur & VanderWeele, 2020, Section 6) was adapted as the criterion value below which publication bias in favor of affirmative results would be considered substantial. In addition, we used the robust variance estimation method to evaluate a worst-case scenario in which only the nonaffirmative ES entries were used to compute the overall ES that can be observed. If this worst-case estimate of the meta-analytic ES approaches the null or reverses the direction of its value, it could be interpreted that publication bias (favoring affirmative results) could potentially attenuate the observed overall ES substantially. To add robustness to our overall sensitivity analysis of publication bias, we also reported (see Supplementary Material 2) the results of a trim-and-fill analysis (Duval & Tweedie, 2000) as well as the *p*-curve method (Simonsohn et al., 2014) that corrected any ES overestimation on the assumption that publication bias from inclusion of small studies with large ES values or selective reporting in the form of *p*-hacking was present among the included studies. Results for both the set of included studies with outliers and the set of included studies without outliers are provided for comparison.

Moderator Variable Analysis

Moderator variables, determined a priori, included participants' age group, health status, and skill level. Multivariable metaregression analyses with random-effects models using a restricted maximum likelihood estimator were conducted to examine whether any or a combination of three categorical variables (i.e., age group, health status, and skill level) might predict Hedges' g value differences between EF and IF, separately for motor performance, retention learning, and transfer learning. In line with the primary use of metaregression for exploring heterogeneity, all included studies (inclusive of outliers) were used for this computation to preserve native variability across studies (Baker et al., 2009). Statistical significance was considered with an alpha level of .050.

Results

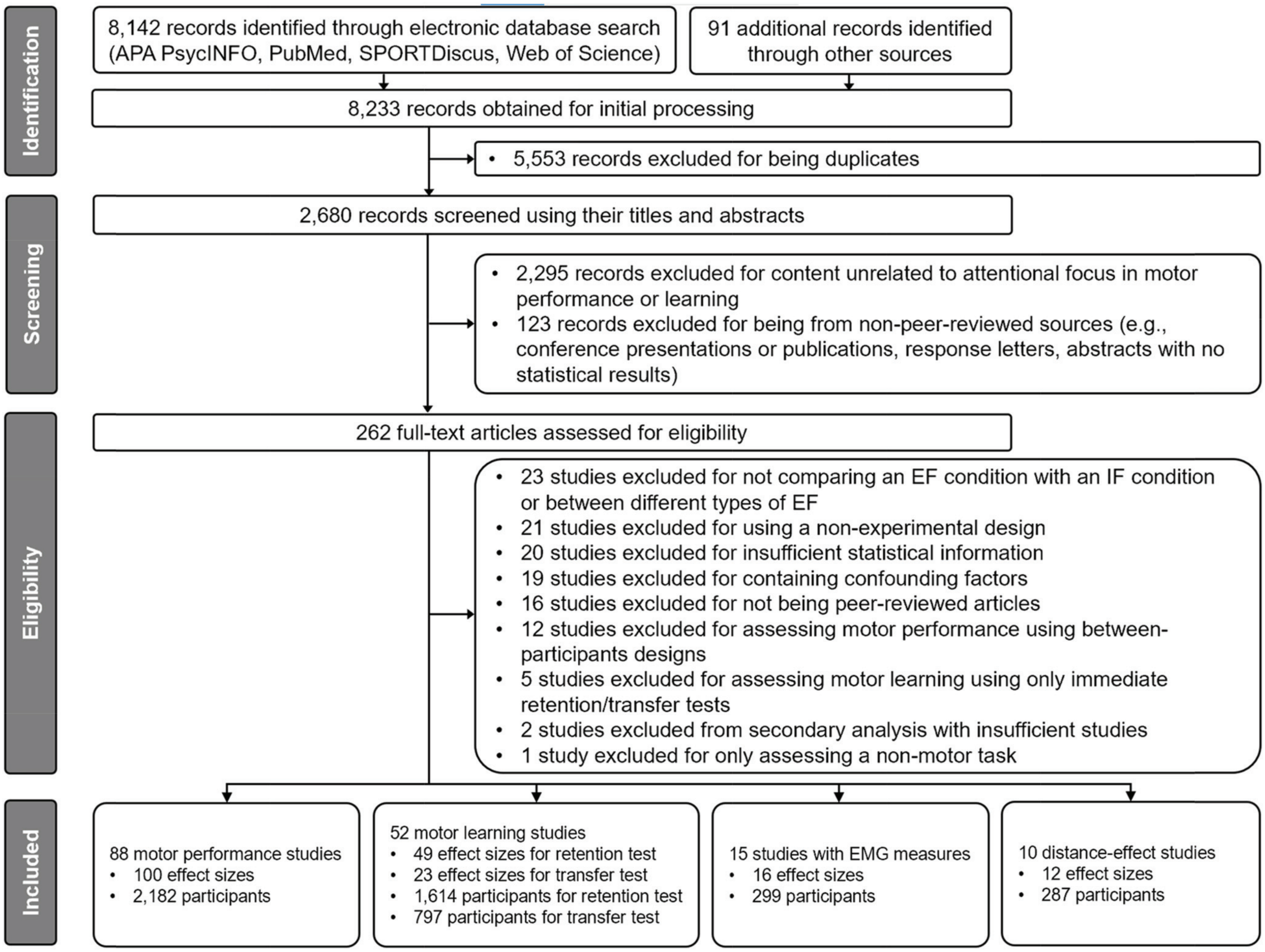
A flowchart depicting the various stages of the study selection process is shown in Figure 1. The initial search generated 8,142 records from four electronic databases. Ninety-one relevant records from other sources such as the reference lists of retrieved articles and the personal archive of GW were added. Based on the preliminary screening of titles and abstracts after removal of duplicates, we further removed records that investigated attentional phenomena (e.g., breadth of attention, attentional resources) or independent variables other than the form of focus of attention of interest in this study (i.e., all movement task-related and body-focused or external effect/target-focused), including distraction cues and dissociation/association forms of attentional focus. We also omitted records published in conference proceedings or presented as research posters and other nonpeer reviewed forms. A total of 262 records remained for which the content of their full-text articles was inspected with reference to the inclusion and exclusion criteria. Following this full-text review, a total of 119 studies were excluded for various reasons, resulting in a total of 143 included studies; their characteristics are summarized in the Appendix.

Of the 143 included studies, 88 compared motor performance between EF and IF using a behavioral outcome measure. Eleven of them used multiple experiments. The majority of these studies involved participants from the adult age group (77.5% vs. 10.1% for children, and 12.4% for the older adult age group). Nine studies used participants with various clinical conditions. Novices (56.4%) were most commonly involved in these 88 studies and the proportion of studies using experienced participants (22.3%) was similar to that using experts (21.3%). Sample sizes per age group, health status, and skill category, ranged from four to 98 participants. Jumping as a motor task was used in the largest number of studies.

As for the 52 included papers that compared motor learning between EF and IF using a behavioral outcome measure, four of them used multiple experiments. Child participants (42.6%) were almost as often involved as adult participants (51.9%), and in many more studies than older adults (5.5%). Nine studies had participants with various clinical conditions. Most of these 52 studies used participants who were novices (86.5%) as compared to experienced participants (13.5%); no participant with expert skill level was involved as might be expected for motor learning studies. Retention and transfer test results were used from 46 and 21 studies, respectively, with 17 of these studies contributing both types of test results. Sample sizes per age group, health status, and skill category, ranged from 10 to 100 participants. Balancing was the most used motor task for learning.

Fifteen papers compared motor performance between EF and IF using EMG as an outcome measure. Three of them used multiple experiments. All participants were adults. None of these studies involved participants with clinical conditions. Participants who were

Figure 1
Flowchart on the Selection of Studies



Note. EF = external focus; EMG = electromyographic; IF = internal focus.

considered to be novices (53.3%) were nearly as commonly used as experienced participants (40.0%); only one study used experts (6.7%). Sample sizes per age group, health status, and skill category, ranged from eight to 30 participants. These studies predominantly used tasks involving *simple, relatively constrained* (by task requirements, equipment, or permissible joint motions), *planar* movements with more (IF) or less (EF) muscle activation (e.g., ankle plantarflexion, elbow flexion, finger abduction), as well as several studies with *more complex, less constrained* movements (e.g., dart throwing, free-throw shooting, golf putting) in which there is typically an accuracy goal, but no particular demand on movement form.

All the 10 studies comparing motor performance between distal EF and proximal EF using a behavioral outcome measure were single-experiment studies. Almost all these studies used adult participants (90.0%), with only one study involving child participants (10.0%); no older adult participants were involved. None of the participants had a clinical condition. Novices (58.3%) were most commonly used with a similar number of studies involving experienced participants (16.7%) and experts (25.0%). Sample sizes per age group, health status, and skill category, ranged from four to 54 participants. Jumping was the most commonly used motor task.

Among the 119 excluded studies, several studies compared IF with only non-EF conditions or no comparison between different types of EF cue (23 studies), had no experimental manipulation of attentional focus (21 studies), or had insufficient statistical information (20 studies). Other studies were excluded because they contained confounding conditions (19 studies), such as instructions referring to different aspects of the task in the EF versus IF conditions (e.g., Canning, 2005), the presence of secondary tasks (e.g., Castaneda & Gray, 2007; MacMahon & Charness, 2014; Schücker, Hagemann, & Strauss, 2013), or unspecified attentional focus instructions (Miçooğulları et al., 2012). Furthermore, we excluded studies that were nonpeer-reviewed (16 studies), assessed motor performance using a between-participants design (12 studies), assessed motor "learning" using only immediate (less than 24 hr after practice) retention and/or transfer tests (five studies), were meant for distance-effect analysis with insufficient number of motor learning studies (two studies), or assessed a non-motor task (one study). The list of excluded studies and their associated reasons can be found in Supplementary Material 1.

Motor Performance

A total of 88 studies involving 2,182 participants compared motor performance as a function of EF versus IF, using within-participant designs, and met the inclusion criteria. Twelve studies each included more than one subgroup (Duke et al., 2011; Fasoli et al., 2002; Freudenheim et al., 2010; Halperin et al., 2017; Ille et al., 2013; Jazaeri et al., 2018; Maurer & Munzert, 2013; McNevin et al., 2013; Pelleck & Passmore, 2017; Perkins-Ceccato et al., 2003; Stambaugh, 2017; Winkelman et al., 2017), yielding a total of 100 ES. The overall ES indicated that EF resulted in significantly more effective performance than did IF (Hedges' g value = 0.379; 95% CI [0.294, 0.465], $p < .001$, $Q(99) = 417.4$, $p < .001$, $I^2 = 76.3\%$, $\tau^2 = 0.219$; forest plot shown in Figure 1 of Supplementary Material 3). Subgroup analysis showed that EF performance was significantly more effective compared to IF performance for both the set of 11 ES entries with moderate risk of bias, Hedges' g value = 0.399, 95% CI [0.250, 0.547], $p < .001$, and the set of 89 ES entries with low risk of bias, Hedges' g value = 0.405; 95% CI [0.284, 0.525], $p < .001$.

Potential small-study effects were observed as demonstrated by funnel plot asymmetry (shown in Figure 2a) and a significant Egger's regression test result, $t(98) = 4.113$, $p < .001$.

Statistical outlier analysis detected 18 entries (from 17 studies) with extreme ES (Durham et al., 2014; Hosseiny et al., 2014; Jazaeri et al., 2018; Klostermann et al., 2014; Lisman & Sadagopan, 2013; Lohse et al., 2010; Lohse et al., 2011; Marchant, Greig, et al., 2009; Maurer & Munzert, 2013; Nadzalan et al., 2015; Neumann & Piercy, 2013; Oki et al., 2018; Pelleck & Passmore, 2017; Porter, Nolan, et al., 2010; Rossettini et al., 2017; Saemi et al., 2016; Sherwood et al., 2014) and upon their removal, with a remaining total of 73 studies involving 1,824 participants, EF contributed to more effective performance as compared with IF (Hedges' g value = 0.264, 95% CI [0.217, 0.310], $p < .001$, $Q(81) = 93.8$, $p = .156$, $I^2 = 13.7\%$, $\tau^2 = 0.006$).

Sensitivity analysis results of the selection-model approach of Mathur and VanderWeele (2020) showed that there were 24 affirmative ES entries and 58 nonaffirmative ES entries after the removal of 18 outlier ES entries (as seen in Figure 3). No amount of publication bias could attenuate the observed overall ES (Hedges' g value = 0.264) to the null value for which the use of EF resulted in significantly more effective performance than IF. Under the assumed robust random-effects model specification, the worst-case estimate of the overall ES for only the 58 nonaffirmative ES entries also showed that performance using EF was statistically more effective than performance using IF (Hedges' g value = 0.159, 95% CI [0.123, 0.195], $p < .010$).

Motor Learning—Retention Test

Forty-seven studies with 1,614 participants compared motor learning as a function of EF versus IF, using retention tests (with between-participants designs), and met the inclusion criteria. Two studies used more than one subgroup each (Becker & Smith, 2013; Emanuel et al., 2008), yielding a total of 49 ES. The overall ES indicated that an EF resulted in significantly more effective learning than an IF (Hedges' g value = 0.687, 95% CI [0.454, 0.919], $p < .001$, $Q(48) = 236.4$, $p < .001$, $I^2 = 82.4\%$, $\tau^2 = 0.538$; forest plot shown in Figure 2 of Supplementary Material 3). Subgroup analysis indicated that EF practice was significantly more effective compared to IF practice in influencing learning outcomes for both the set of 21 ES entries with moderate risk of bias, Hedges' g value = 0.656; 95% CI [0.243, 1.068], $p = .002$, and the set of 28 ES entries with low risk of bias, Hedges' g value = 0.686; 95% CI [0.428, 0.945], $p < .001$.

Potential small-study effects were observed as indicated by both funnel plot asymmetry (shown in Figure 2b) and Egger's regression test result that reached statistical significance, $t(47) = 2.900$, $p = .006$.

Ten entries (from 10 studies) with extreme ES (Agar et al., 2016; Ahmad et al., 2013; Becker & Smith, 2013; Emanuel et al., 2008; Perreault & French, 2015; Samsudin & Low, 2017; Tse, 2017; Tsetseli et al., 2018; Wulf et al., 2001; Wulf, Weigelt, et al., 2003) were identified by statistical outlier analysis for removal, resulting in a remaining total of 40 studies involving 1,274 participants and an overall ES indicative of EF contributing to more effective learning (retention performance) in comparison to IF (Hedges' g value = 0.583, 95% CI [0.425, 0.741], $p < .001$, $Q(38) = 82.5$, $p < .001$, $I^2 = 53.9\%$, $\tau^2 = 0.125$).

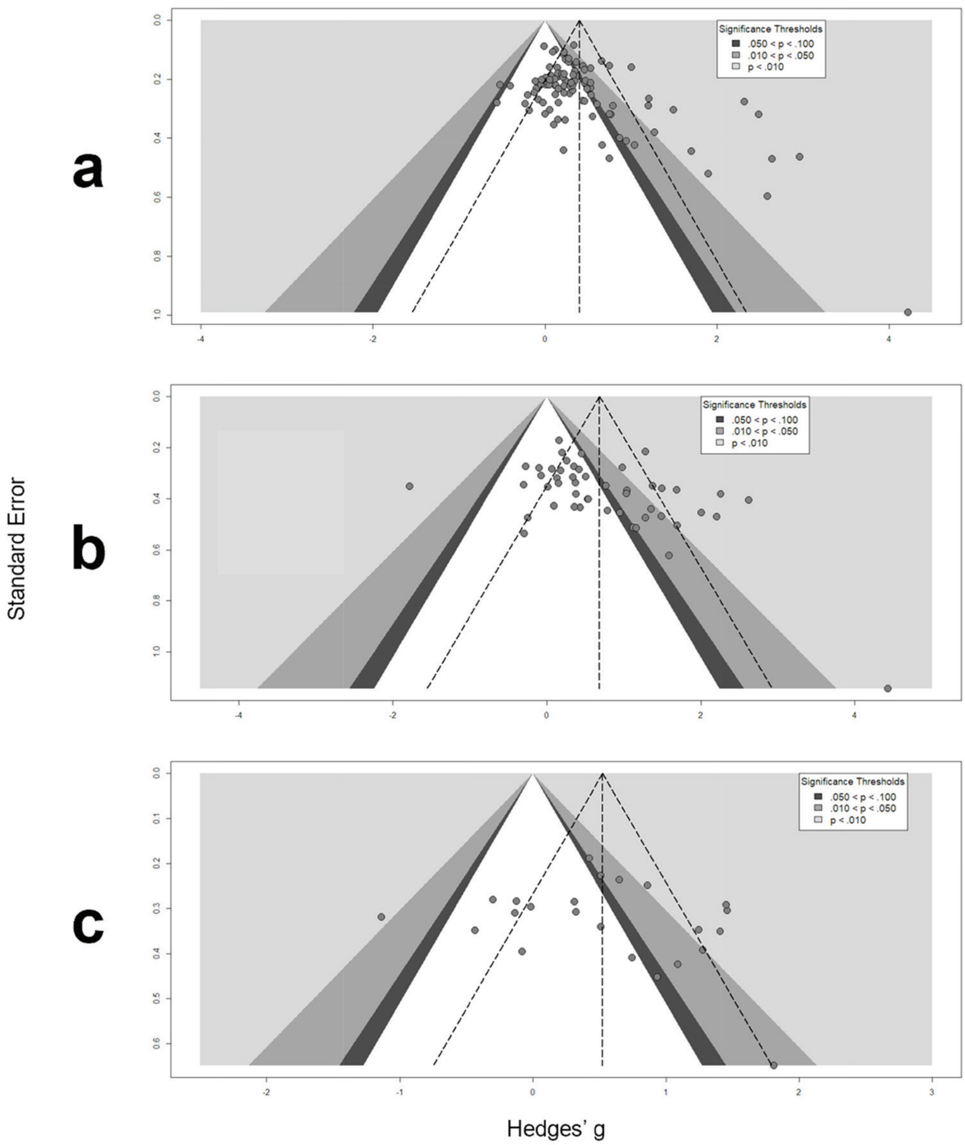
As seen in Figure 4, there were 16 affirmative ES entries and 23 nonaffirmative ES entries, after the removal of 10 outlier ES entries, from the sensitivity analysis results of the selection-model approach of Mathur and VanderWeele (2020). No amount of publication bias could attenuate the observed overall ES (Hedges' g value = 0.583) to the null value for which an EF resulted in significantly more effective learning than an IF as measured by retention tests. Under the assumed robust random-effects model specification, the worst-case estimate of the overall ES for only the 23 nonaffirmative ES entries showed that EF contributed to more effective learning than IF (Hedges' g value = 0.248, 95% CI [0.156, 0.340], $p < .010$).

Motor Learning—Transfer Test

A total of 22 between-participants studies with the involvement of 797 participants met inclusion criteria and compared motor learning as a function of attentional focus by using transfer tests. One study had more than one subgroup (Emanuel et al., 2008). Thus, a total of 23 ES were available. The overall ES indicated that an EF resulted in superior transfer performance relative to an IF (Hedges' g value = 0.525, 95% CI [0.235, 0.815], $p < .001$, $Q(22) = 102.1$, $p < .001$, $I^2 = 80.7\%$, $\tau^2 = 0.391$; forest plot shown in Figure 3 of Supplementary Material 3). Subgroup analysis showed that EF practice was significantly more effective compared to IF practice in influencing learning outcomes for both the set of 14 ES entries with moderate risk of bias, Hedges' g value = 0.555; 95% CI [0.151, 0.958], $p = .007$, and the set of nine ES entries with low risk of bias, Hedges' g value = 0.461; 95% CI [0.055, 0.867], $p = .026$.

Figure 2

Contour-Enhanced Funnel Plots for Publication Bias Analysis of Studies Comparing External and Internal Foci in Primary Meta-Analyses



Note. (a) Motor performance, (b) motor learning using retention tests, and (c) motor learning using transfer tests.

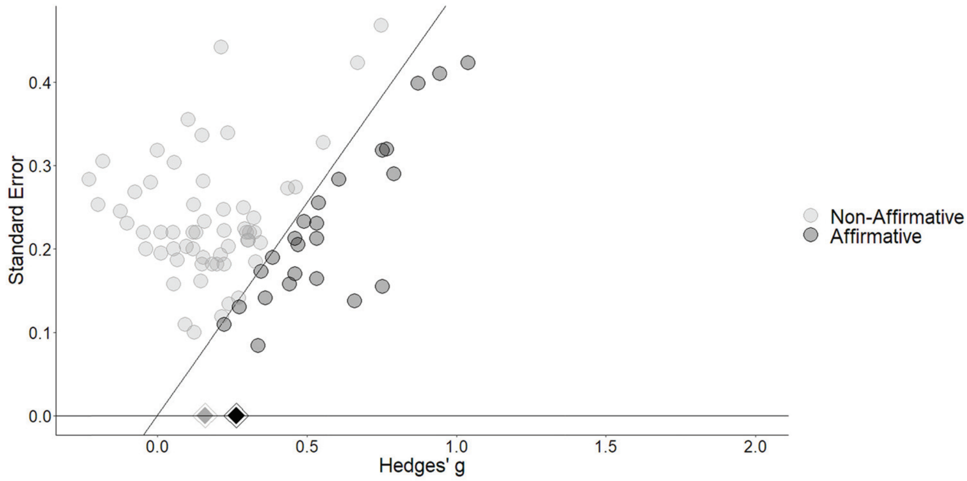
Small-study effects were not observed, as indicated by a symmetric funnel plot (shown in Figure 2c) and a nonsignificant Egger's regression test result, $t(21) = 0.823$, $p = .420$.

Statistical outlier analysis detected three entries (from three studies) with extreme ES (Abdollahipour et al., 2019; Kalkhoran & Shariati, 2014; Tse, 2017). Upon removal, with a remaining total of 19 studies involving 683 participants, the overall ES indicated that EF contributed to more effective learning as compared to IF as measured by transfer test performance (Hedges' g value = 0.584, 95% CI [0.325, 0.842], $p < .001$, $Q(19) = 61.0$, $p < .001$, $I^2 = 68.8\%$, $\tau^2 = 0.237$).

Sensitivity analysis results using the selection-model approach of Mathur and VanderWeele (2020) showed that there were 11 affirmative ES entries and nine nonaffirmative ES entries, after the removal of three outlier ES entries (as seen in Figure 5). No amount of publication bias could attenuate the observed overall ES (Hedges' g value = 0.584) to the null value for which the use of EF during practice resulted in superior learning outcomes as measured by transfer test performance. Under the assumed robust random-effects model specification, the worst-case estimate of the overall ES for only the nine nonaffirmative ES entries showed that EF and IF had the same learning outcomes (Hedges' g value = 0.095, 95% CI [−0.194, 0.383], $p > .100$).

Figure 3

Significance Funnel Plot for Publication Bias Analysis of Studies Comparing External and Internal Foci in Motor Performance



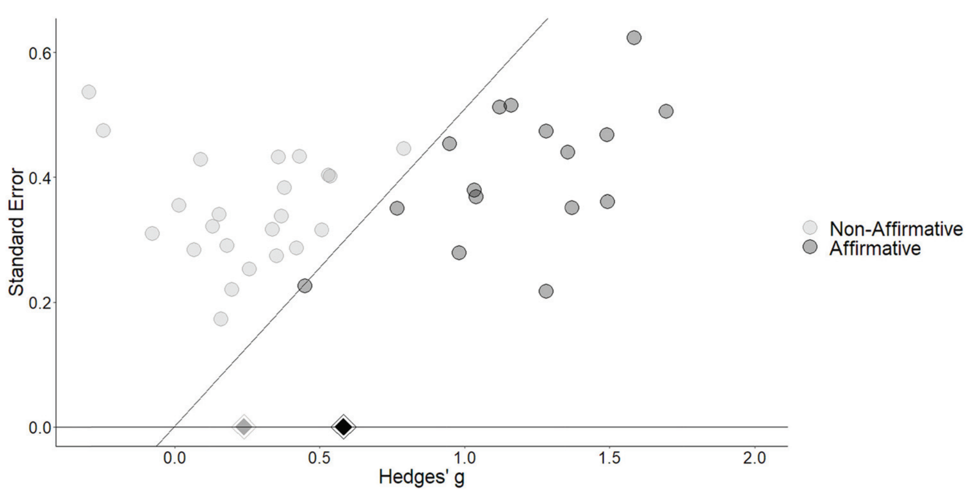
Note. ES entries on the diagonal line have a *p*-value of .050; gray diamond represents estimate of the overall ES only for nonaffirmative ES entries; black diamond represents estimate of the overall ES for all ES entries.

Moderator Analyses

The three moderator variables were analyzed singularly and collectively in performance and learning models using multivariable metaregression analyses with considerations for two-way interactions (e.g., age group × health status, age group × skill level, health status × skill level). Analysis of the motor performance studies was carried out after the removal of one study with no age information (Perkins-Ceccato et al., 2003). The overall model was not significant, $p = .923$, $R^2 = 0.00\%$. Age group, health status, skill level, and their pairwise comparisons were found to have no modifying effects on ES differences between EF and IF for motor performance, all $p > .100$ (see Table 1 for details). Likewise, for motor learning as measured by retention tests, there was no significant overall model, $p = .854$, $R^2 = 0.00\%$. Neither age group, health status, skill level, nor any of their pairwise comparisons were significant effect modifiers for the observed ES differences between EF and IF, all $p > .100$ (see Table 1 for details). Of the eligible learning studies using transfer tests, only the comparison of children with adults was possible in the evaluation of age group as a moderator variable because there was only one study involving older adults (Landers et al., 2016), which did not meet the minimum-of-five

Figure 4

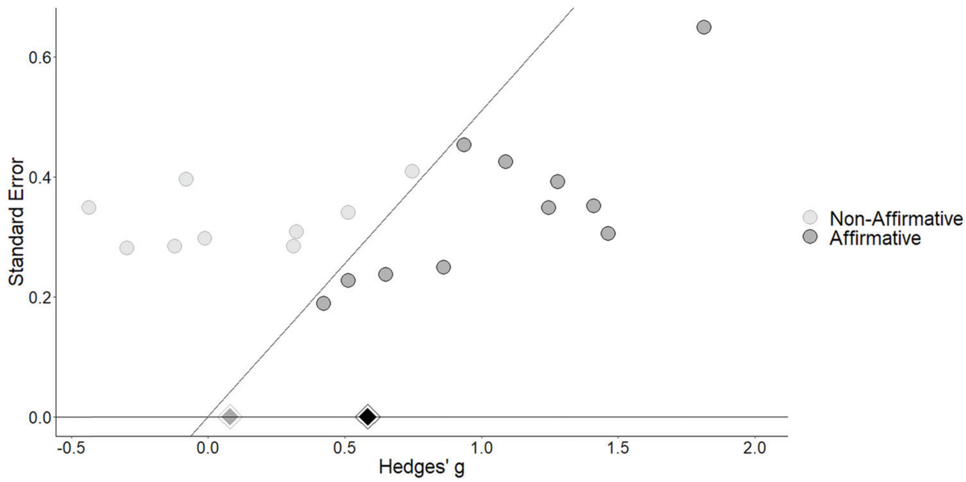
Significance Funnel Plot for Publication Bias Analysis of Studies Comparing External and Internal Foci in Retention Tests



Note. ES entries on the diagonal line have a *p*-value of .050; gray diamond represents estimate of the overall ES only for nonaffirmative ES entries; black diamond represents estimate of the overall ES for all ES entries.

Figure 5

Significance Funnel Plot for Publication Bias Analysis of Studies Comparing External and Internal Foci in Transfer Tests



Note. ES entries on the diagonal line have a *p*-value of .050; gray diamond represents estimate of the overall ES only for nonaffirmative ES entries; black diamond represents estimate of the overall ES for all ES entries.

recommendation of Jackson and Turner (2017). Consequently, only one other study involving experienced participants remained (Makaruk et al., 2012) with no studies involving participants with an expert skill level. Thus, the moderator effects of only two categorical variables, namely, age group (children vs. adults) and health status (with or without clinical condition), were determined for motor learning studies with transfer test results. Again, no significant overall model was found, $p = .366$,

Table 1

Multivariable Metaregression Analyses for Three Identified Moderator Variables (Age Group, Health Status, and Skill Level)

Performance model ($m = 88$, $n = 2{,}182$, $k = 100$)	β_{coeff}	95% CI	*p*-value
Intercept	0.320	[−0.152, 0.791]	.184
Adults	0.130	[−0.376, 0.636]	.614
Older adults	−0.196	[−1.089, 0.697]	.666
With clinical condition	0.345	[−0.517, 1.207]	.432
Experienced	−0.083	[−1.250, 1.084]	.889
Expert	−0.460	[−1.349, 0.429]	.311
Two-way interactions			
Adults—Experienced	0.066	[−1.141, 1.273]	.915
Older adults—Experienced	0.169	[−1.325, 1.662]	.825
Adults—Expert	0.488	[−0.458, 1.434]	.312
Adults—With clinical condition	−0.042	[−1.508, 1.423]	.955
With clinical condition—Experienced	−0.267	[−1.769, 1.235]	.727
Retention learning model ($m = 47$, $n = 1{,}614$, $k = 49$)	β_{coeff}	95% CI	*p*-value
Intercept	0.566	[0.116, 1.016]	.014
Adults	0.165	[−0.421, 0.750]	.582
Older adults	0.473	[−1.276, 2.223]	.596
With clinical condition	0.151	[−0.892, 1.194]	.777
Experienced	0.789	[−0.477, 2.055]	.222
Two-way interactions			
Adults—Experienced	−0.308	[−2.091, 1.476]	.735
Older adults—Experienced	−0.847	[−3.511, 1.817]	.533
Adults—With clinical condition	−0.686	[−2.149, 0.778]	.358
Older adults—With clinical condition	−1.029	[−3.558, 1.500]	.425
Transfer learning model ($m = 22$, $n = 797$, $k = 23$)	β_{coeff}	95% CI	*p*-value
Intercept	0.549	[0.118, 0.979]	.013
Adults	−0.036	[−0.656, 0.728]	.919
With clinical condition	−0.649	[−1.769, 0.470]	.256
Two-way interaction			
Adults—With clinical condition	1.528	[−0.345, 3.401]	.110

Note. m = number of studies; n = number of participants; k = number of effect sizes.

R^2 = 3.14%. Age group and health status, and their interaction, were not significant moderators, all $p > .100$ (see Table 1 for details).

Secondary Analyses

EMG

A total of 15 studies with 299 participants, using within-participant designs, met the inclusion criteria for comparing EMG activation. One study had more than one subgroup (Pelleck & Passmore, 2017), giving a total of 16 ES. The overall ES indicated that EF resulted in significantly lower EMG activity than did IF (Hedges' g value = 0.758, 95% CI [0.401, 1.116], $p < .001$, $Q(15) = 123.0$, $p < .001$, $I^2 = 89.2\%$, $\tau^2 = 0.448$; forest plot shown in Figure 4 of Supplementary Material 3). Subgroup analysis was not carried out to assess the influence of risk of bias on effect sizes due to the availability of only one ES entry for the moderate-level subgroup.

Funnel plot asymmetry (shown in Figure 6a) as confirmed by a significant Egger's regression test result, $t(14) = 2.389$, $p = .032$, indicated potential small-study effects.

Statistical outlier analysis detected three entries (from three studies) with extreme ES (Greig & Marchant, 2014; Halperin, Hughes, et al., 2016; Kal et al., 2013) and upon their removal, with a remaining total of 12 studies involving 216 participants, the overall ES increased and was indicative of EF contributing to lower muscular activation as compared with IF (Hedges' g value = 0.833, 95% CI [0.453, 1.213], $p < .001$, $Q(12) = 67.7$, $p < .001$, $I^2 = 82.3\%$, $\tau^2 = 0.391$).

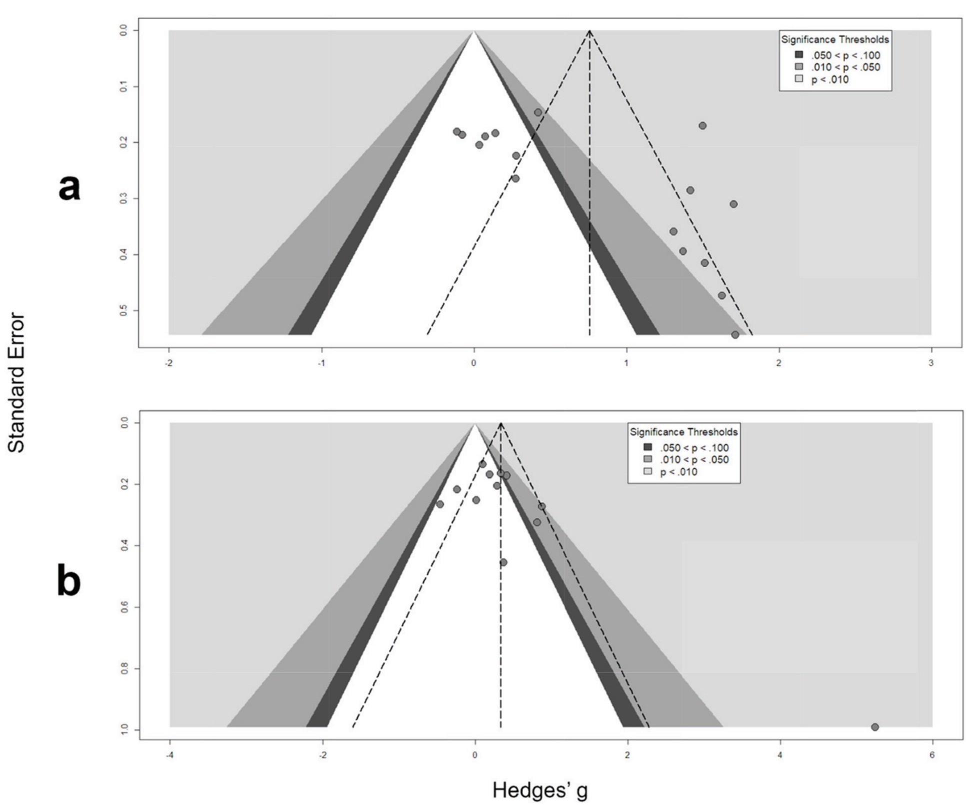
Sensitivity analysis results in the selection-model approach of Mathur and VanderWeele (2020) indicated that there were eight affirmative ES entries and five nonaffirmative ES entries, excluding three outlier ES entries (see Figure 7). No amount of publication bias could attenuate the observed overall ES (Hedges' g value = 0.833) to the null value for which EF resulted in significantly lower EMG activity than did IF. Under the assumed robust random-effects specification, the worst-case estimate of the overall ES for only the five nonaffirmative ES entries also indicated that EF resulted in significantly lower EMG activity than did IF (Hedges' g value = 0.159, 95% CI [0.021, 0.297], $p < .050$; results should be interpreted with caution due to meta-analyzing only five nonaffirmative ES entries).

Distance Effect

Ten within-participant studies involving 287 participants and comparing motor performance as a function of distal versus proximal EF met the inclusion criteria. A total of 12 ES was obtained because each of two studies used more than one subgroup (Duke et al., 2011; Stambaugh, 2017). A distal EF resulted in significantly

Figure 6

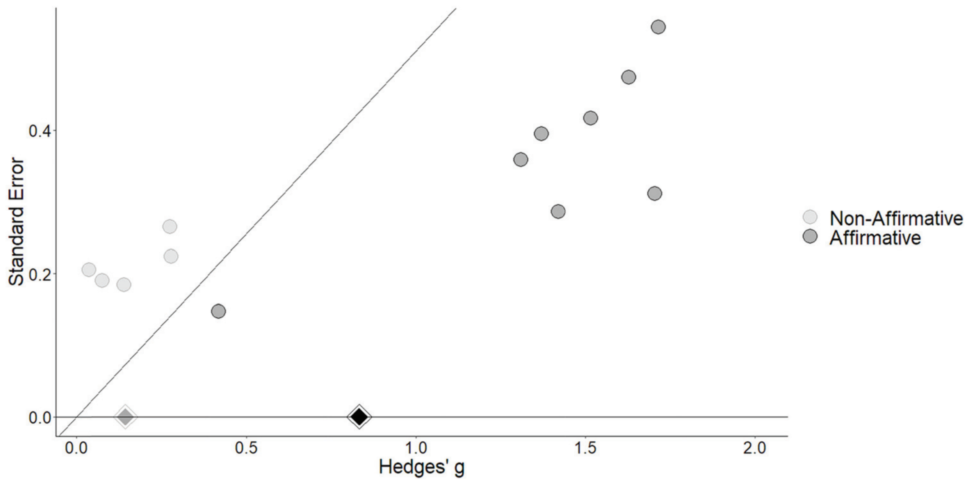
Contour-Enhanced Funnel Plots for Publication Bias Analysis of Studies Comparing External and Internal Foci or Distal and Proximal External Foci in Secondary Meta-Analyses



Note. (a) Studies comparing effects of external versus internal focus on EMG outcome measures and (b) studies comparing effects of distal versus proximal external focus on motor performance.

Figure 7

Significance Funnel Plot for Publication Bias Analysis of Studies Comparing External Versus Internal Focus on EMG Outcome Measures



Note. EMG = electromyographic. ES entries on the diagonal line have a *p*-value of .050; gray diamond represents estimate of the overall ES only for nonaffirmative ES entries; black diamond represents estimate of the overall ES for all ES entries.

more effective performance than did a proximal EF (Hedges' *g* value = 0.339, 95% CI [0.028, 0.651], $p = .033$, $Q(11) = 49.2$, $p < .001$, $I^2 = 82.8\%$, $\tau^2 = 0.225$; forest plot shown in Figure 5 of Supplementary Material 3). Subgroup analysis revealed that distal EF performance did not differ from proximal EF performance for both the set of five ES entries with moderate risk of bias, Hedges' *g* value = 0.182; 95% CI [0.000, 0.363], $p = .050$, and the set of seven ES entries with low risk of bias, Hedges' *g* value = 0.842; 95% CI [−0.292, 1.976], $p = .146$.

Funnel plot symmetry (shown in Figure 6b) and a nonsignificant Egger's regression test result, $t(10) = 1.997$, $p = .074$, did not indicate bias in the distribution of effects.

Statistical outlier analysis identified one entry (from one study) with extreme ES (Lohse et al., 2014) and upon removing this study, resulting in a remaining total of nine studies involving 272 participants, the smaller overall ES was indicative of distal EF contributing to more effective performance in comparison with proximal EF (Hedges' *g* value = 0.224, 95% CI [0.019, 0.429], $p = .032$, $Q(10) = 23.5$, $p = .009$, $I^2 = 57.4\%$, $\tau^2 = 0.069$).

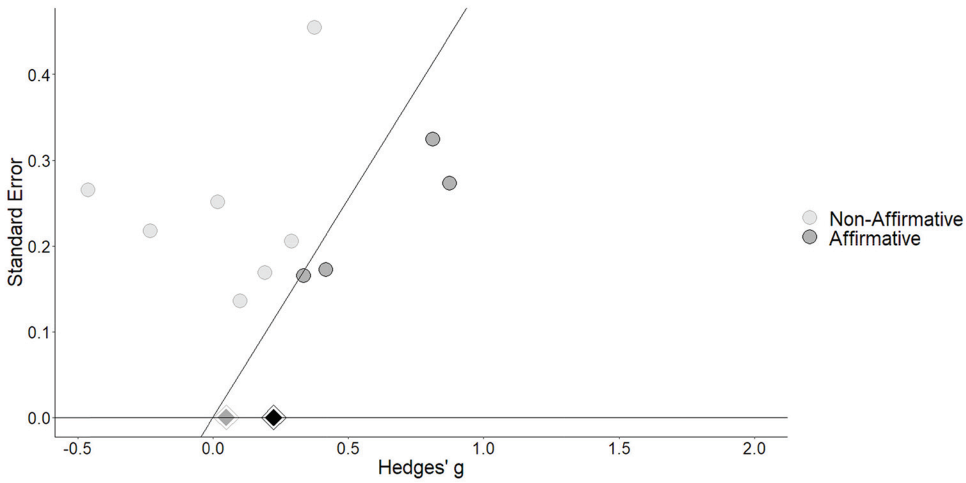
As presented in Figure 8, there were four affirmative ES entries and seven nonaffirmative ES entries, after the removal of one outlier ES entry, from the distal/proximal EF sensitivity analysis results using the selection-model approach of Mathur and VanderWeele (2020). No amount of publication bias could attenuate the observed overall ES (Hedges' *g* value = 0.224) to the null value for which a distal EF resulted in significantly more effective performance than did a proximal EF. Under the assumed robust random-effects model specification, the worst-case estimate of the overall ES for only the seven nonaffirmative ES entries indicated that performance using distal EF did not differ from performance using proximal EF (Hedges' *g* value = 0.033, 95% CI [−0.221, 0.288], $p > .100$).

Discussion

In support of more than two decades of empirical work and several narrative reviews as well as limited-scope meta-analyses on the effects of attentional focus, we conducted the first comprehensive meta-analytic review of those findings. Specifically, we carried out a series of three primary meta-analyses to evaluate effects of an EF in comparison to an IF on immediate motor performance and more sustained or generalized learning with delayed tests (retention, transfer). Meta-analyses of motor performance included 82 ES (after the removal of 18 outliers) in which all participants performed under both attentional focus conditions. The results showed that performance in the EF condition was more effective than that in the IF condition, with a small overall ES (Hedges' *g* value = 0.264). Meta-analyses of motor learning, as measured by retention tests, included 39 ES (after the removal of 10 outliers). Analysis of retention test performance yielded a medium overall ES (Hedges' *g* value = 0.583) in favor of an EF. Evaluation of transfer test performance under new task conditions included 20 ES (after the removal of three outliers) and resulted in a similar medium-sized overall ES (Hedges' *g* value = 0.584), also favoring EF. Effects of moderator variables of interest (age group, health status, and skill level) on performance or learning were nonsignificant, suggesting broad generalizability of the attentional focus effect. In addition to measures of overall performance, we conducted secondary meta-analyses on neuromuscular efficiency (EMG) involving 13 ES (after the removal of three outliers) and the distance of the EF (distal vs. proximal) involving 11 ES (after the removal of one outlier). Reduced EMG activity, in the context of superior motor performance with EF, suggests that neuromuscular efficiency was enhanced by EF relative to IF conditions, with a large overall ES (Hedges' *g* value = 0.833). The meta-analysis of the distance effect demonstrated that EF benefits for motor performance were larger for distal relative to more proximal external foci, with a small overall ES (Hedges' *g* value = 0.224).

Figure 8

Significance Funnel Plot for Publication Bias Analysis of Studies Comparing Distal Versus Proximal External Focus in Motor Performance



Note. ES entries on the diagonal line have a *p*-value of .050; gray diamond represents estimate of the overall only for nonaffirmative entries; black diamond represents estimate of the overall for all entries.

Generalizability of the EF Benefits

Overall, it is remarkable how a small difference in instructions and feedback directing the performer's concentration can have a significant influence on immediate performance played out in the coordination of brain and limbs, and the efficiency with which movements are executed, as well as longer-term effects on learning. Furthermore, benefits of adopting an EF are seen for tasks ranging from simple ankle movements of plantar flexion (Lohse et al., 2011) to complex skills such as driving a golf ball (An et al., 2013; Christina & Alpenfels, 2014) or playing classical music (Mornell & Wulf, 2019), from children doing tuck rolls (Koufou et al., 2013) to older adults performing a tracking task (McNevin et al., 2013), and from high-level athletes performing maximum-effort punches (Halperin et al., 2017) to persons after stroke grasping objects (Fasoli et al., 2002). A focus on the task goal (e.g., hitting a target) or intended movement effect (e.g., ball trajectory) seems to optimize performance and learning—independent of performer characteristics.

The generalizability of the advantage of an external compared with an internal focus as evidenced by the wide range of tasks (e.g., simple to complex, short to long duration, closed to open environments) and performance measures (e.g., balance, accuracy, force), age groups (children to older adults), skill levels (novices to experts), and (dis)abilities or health status (healthy to impaired) demonstrated in individual studies, is in line with our moderator analyses. None of the potential moderator variables (age group, health status, and skill level) modified the differential effects between EF and IF on the performance and learning of motor skills. Thus, variations in ES were not associated with any of these variables. These results underscore the wide-ranging effectiveness of an EF.

Across all studies, ES varied considerably, though. Before accounting for outliers with extremely small or large ES values, indices of heterogeneity were high (I^2 = 76.3%−89.2%) and ranged from low to high (I^2 = 13.7%−82.3%) after identified outliers were removed from the analysis, suggesting additional sources of variability in ES. What may explain differences in ES? A cardinal feature of the attentional focus literature is the diverse set of motor tasks, measures of performance, and performer experience or conditions, employed. While consistent with a generalizable and ecologically valid effect, these aspects are often nested, such that certain tasks with relevant measures are likely to be evaluated within participants of a given age group or health status. Older adults are seldom asked to toss beanbags or perform soccer throw-ins, for example,

Other candidates for heterogeneity influence are the content of instructions (or feedback) used to induce an EF versus an IF, again typically specific and intertwined with the nature of examined tasks. Ideally, in a strict test of attentional focus effects, instructions should differ only with regard to the type of attentional focus they are designed to induce. IF instructions should contain reference to at least one body part, while EF instructions should not include such references but should instead direct attention to the intended movement effect. Moreover, instructions should also be similar in terms of the length of the instructions/feedback or number of instructional/feedback elements, cues, or statements. Also, they should not differ with respect to other confounding conditions such as the use of visual information that might be encouraged by one set of instructions (e.g., EF) but not the other (e.g., IF). While many researchers have applied these criteria, in a number of studies some of these issues may have contributed to variable results. In the present meta-analyses, the most problematic studies were excluded (see Supplementary Material 1). Nevertheless, we adopted a relatively conservative approach and included other studies that contained confounding conditions. For example, in some studies, the sheer number of instructional statements, vagueness or lack of comparability of EF and IF instructions, and different numbers of instructions in each condition (e.g., Emanuel et al., 2008; Perkins-Ceccato et al., 2003; Zentgraf & Munzert, 2009), may explain a lack of group differences. Wulf (2013) provided a detailed discussion of methodological issues associated with attentional focus studies. Nonetheless, the extent of performance or learning tolerance for instructional mixing or deviation from "purity" in attentional focus wording may be regarded as an empirical question.

Performance Versus Learning

ES for effects on motor performance tended to be somewhat lower than those seen for learning (retention, transfer). In addition to experimental design distinctions (i.e., within-participant vs. between-participants for performance and learning, respectively) and the minimization of potential interindividual influences in the former, there may be several reasons for the relative difference. First, in studies examining performance per se, participants were often familiar or well-practiced with regard to the tasks, which could be seen as sometimes habitual or virtually "automatic," and continuous in nature: runners or trained athletes running (Schücker et al., 2009; Winkelman et al., 2017; Ziv et al., 2013), swimmers swimming (Stoate & Wulf, 2011), cyclists cycling (Schücker et al., 2016), boxers and kickboxers punching (Halperin et al., 2017), older people walking (Yogev-Seligmann et al., 2017), or musicians playing alternating notes (Stambaugh, 2017). In contrast, in learning studies, researchers typically select tasks that are novel to participants and often somewhat challenging. Thus, there is more room for improvement and for attentional focus instructions (or other independent variables) to show their effects.

Second, in performance studies, all participants perform under all attentional focus conditions (sometimes including a control condition as well) in the same experimental session. Thus, it may be somewhat challenging for them to shift their attentional focus from internal (e.g., on the finger used to touch a rung; Wulf & Dufek, 2009) on one block of trials to external (e.g., on the rung to be touched with finger) on another block and maintain that focus on all trials within that block.

Third, adopting a certain focus may be particularly difficult when an IF is compared with a proximal EF (e.g., fingers vs. keys when playing a woodwind instrument, Stambaugh, 2017; motion of the arm vs. release of the dart in dart throwing, Lohse et al., 2014). Our conservative approach of choosing the EF cue that most closely matched the IF cue—almost inevitably a proximal EF cue—applied to several performance studies. These factors could at least partially explain the differential magnitude of ES in performance relative to learning studies.

Distance Effect

Our secondary meta-analysis on the distance effect, first demonstrated by McNevin et al. (2003), revealed that a distal EF is more effective than a proximal EF (Hedges' g value = 0.224). That is, concentrating on a movement effect that occurs at a greater physical distance from one's body increases the performance advantage compared to focusing on a movement effect that is in closer proximity to the body. A distal EF has also been shown to increase the degree of automaticity in movement control, as measured by the mean power frequency of balance adjustments (McNevin et al., 2003). The tasks used in distance effect evaluations encompassed a wide range of activities such as jumping (Coker, 2018; Marchant, Griffiths, et al., 2018; Porter et al., 2013), golf putting (Kearney, 2015), musical performance (Stambaugh, 2017), dart throwing (Lohse et al., 2014; McKay & Wulf, 2012), and landing mechanics (Raisbeck & Yamada, 2019). Together, these findings suggest that the distance effect is reliable and generalizable. Concentration on targets farther from the body may better facilitate honing in onto a singular ultimate goal, an act potentially imbued with motivational significance (Wulf & Lewthwaite, 2016). Focus on a more distal target may also create greater brain-mind clarity, eschewing potential "noise" or distractions from multiple neuromuscular subgoals, some of which may be pursued in parallel. Such attention away from the body may also support separation from relatively accessible self-referential activations (Yin et al., 2019).

Mechanisms

Behavioral effects have dominated the attentional focus literature. Some, although more limited, attention has been paid to potential neural or brain-related underpinnings of the EF advantage, particularly those in motor cortex and somatosensory areas (Kuhn et al., 2018; Kuhn et al., 2017; Suzuki & Meehan, 2020; Zentgraf et al., 2009; Zimmermann et al., 2012). Using functional MRI, Zentgraf et al. (2009) examined neural activation differences between groups performing practiced finger sequence movements under external or internal focus instructions. The EF group had greater activation in the primary somatosensory, motor, and insular cortices than the IF group. The methodology, however, did not allow for the determination of whether the activations were of an excitatory or inhibitory nature. In more recent investigations, Kuhn and colleagues used a submaximal fatiguing finger task and transcranial magnetic stimulation to identify enhanced EMG suppression and increased short-latency intracortical inhibition in the motor cortex associated with an increased time to task failure and an external focus of attention (Kuhn et al., 2017). In a task with maximal voluntary index finger contraction, increased surround inhibition was found in motor cortex areas associated with muscles not directly involved in the task when an EF was used (Kuhn et al., 2018).

Thus, studies of brain activation have been limited to those using finger movements that can be performed in a scanner. Yet, the findings showing increased inhibition or suppression of activity in somatosensory circuits, and antagonist or adjacent muscles can be seen as consistent with greater efficiency or less opposition for the prime mover. Effects such as those of a neuromuscular (EMG) and cardiovascular nature are also consistent with activity reflecting greater systemic efficiency. The results of our secondary meta-analysis related to EMG activity—which yielded an ES equivalent to a Hedges' g value of 0.833—support the view that EF facilitates neuromuscular efficiency for the enhancement of motor performance, in terms of lower activity in the agonist muscle or cocontraction between agonist and antagonist muscles of the primary motor effector for a given task, as compared with IF.

Connections between the movement intent and movement effect via neurophysiological and neuromuscular activation or suppression in EF conditions can be considered reflections of *goal-action coupling* as described by Wulf and Lewthwaite (2016) in the OPTIMAL theory of motor learning. In that theory, an external attentional focus is featured as one of three optimizing factors (the others being enhanced expectancies and autonomy support) in performance and learning. Disruptions to efficient goal-action coupling in IF conditions might be explained by more conscious constraint of the motor system in attempting to control movement processes (Wulf et al., 2001), with concomitant additional demand for coordination of these processes to produce a coherent response. Alternatively, or complementarily, an EF may be preventative, reducing accessibility to afferent information (Suzuki & Meehan, 2020), potential self-referential processing, or activation of a self-invoking trigger associated with (IF) references to one's own body (McKay et al., 2015; Wulf & Lewthwaite, 2010; Yin et al., 2019). Increased confidence that accrues with effective performance and ease of movement may result in additional performance and learning benefits (Wulf & Lewthwaite, 2016).

Attention has not yet been directed to the cognitive-neural interface, which may initiate the brain activity that follows distinctions in instructional wording (Bréchet et al., 2019; González-García et al., 2021). Further, consideration can be given to the integrative temporal and whole brain involvement, or functional connectivity, and to whole motor system engagement, related to external attentional focus in the facilitation of movement in its many contexts.

Limitations

We limited our review to peer-reviewed and published studies only, and did not include conference papers, theses, or other gray literature works not published in a scientific journal. This approach was adopted to allow peer-review influence to lessen the likelihood of including studies with a potentially high risk of bias. Although it cannot be completely argued that the peer-review process is a foolproof system that routinely ensures only research studies of high methodological quality get to be published, it is considered to be an essential quality-assurance step having been used in the academic process for safeguarding trust in the credibility of scientific research work for more than 300 years (Kelly et al., 2014). Indeed, our decision to omit nonpeer reviewed and unpublished studies resulted in the inclusion of only studies that could be mostly rated to have a low level of risk of bias (75.5% before the removal of outliers; 74.5% after the removal of outliers), with the remaining having a moderate level of risk of bias at the worst (24.5% before the removal of outliers; 25.5% after the removal of outliers). Future meta-analytic studies may want to consider screening the gray literature for suitable studies to compare their degree of methodological rigor with our current sets of included studies. Also, it cannot be completely ruled out that the exclusion of gray literature might have contributed to the influence of publication bias on our findings because it has been found that overall ES values are somewhat overestimated when unpublished data and data from the gray literature are excluded from meta-analyses (Sterling et al., 1995). For an alternative proposition, see Wagner (2021). A visual inspection of the contour-enhanced funnel plots indicated asymmetry in the distribution of ES entries from three sets of included studies (before the removal of outliers), that is, for two primary meta-analyses (on motor performance and motor learning using retention tests) and one secondary meta-analysis (on motor performance using EMG outcome measures). For the first two forementioned meta-analyses, ES entries from studies of statistical significance seem to report larger effects on average. As for the third forementioned meta-analysis, two apparent clusters of ES entries seem to stem from either nonsignificant studies with smaller effects on average or significant studies with larger effects on average. Only the presence of small-study effects (one by-product of publication bias) can be confirmed in these data sets, however, with no clear evidence of publication bias being the sole influence (as discussed below for sensitivity analysis results). For example, the contributions of heterogeneity (as evident from high I^2 indices for the forementioned three meta-analyses: 76.3%, 82.4%, and 89.2%, respectively) and simple chance cannot be ruled out. We have attempted to further assess the potential influence of omitting unpublished studies on our results by conducting sensitivity analyses of publication bias using the Mathur and VanderWeele (2020) approach. To add robustness to the conclusions we can draw from an interpretation of the observed overall ES results, we took the step of removing outliers with extreme ES values prior to carrying out this sensitivity analysis approach. For all five meta-analyses, sensitivity analyses showed that ES contributions having a statistically significant value in the direction of the hypothesized effect would have to be published an *infinite* number of times more than ES contributions that are statistically nonsignificant, or have a zero value or one in the opposite direction of the hypothesized effect, in order to nullify the observed overall ES values. Therefore, in comparison with the empirical benchmark ratio value of 5 (obtained from other meta-analytic studies published in top experimental psychology journals; Mathur & VanderWeele, 2020, Section 6), our meta-analytic results are robust to publication bias. On a conservative note, the worst-case results of two of these sensitivity analyses showing the estimate of the meta-analytic ES for the subset of nonaffirmative motor learning studies using transfer tests and that for the subset of motor performance studies examining the distance effect of EF to be in the positive value range, but including the null value in their confidence intervals, may imply that publication bias (in favor of affirmative results) could have potentially inflated the observed overall ES considerably for these two particular meta-analyses. To facilitate an evaluation of the extent of meta-analytic overestimation due to selective publication and reporting, we also provided publication-bias-corrected ES results obtained via the trim-and-fill and the *p*-curve methods in Supplementary Material 2. A further limitation could stem from the exclusion of studies that were published in languages other than English. Extant literature on the effects of excluding studies published in non-English language from meta-analyses, regardless, does not suggest that this issue may significantly skew our current findings (Moher et al., 2000; Morrison et al., 2012).

Conclusions

This study synthesized and quantified empirical evidence accumulated from over more than two decades of research on the performance and learning effects of attentional focus. We also examined the influence of potential moderating variables, including age group, health status, and skill level. The results demonstrate a superiority of using EF over IF for motor performance and learning, in the absence of significant moderator effects. The attentional focus phenomenon has captured the interests of applied researchers with specific interests in particular motor tasks and sports, performance skills, and the health professions. This widespread interest has perhaps been sparked by the contrast between the EF benefit and the manner in which instructors, coaches, or therapists have typically taught—that is with internally focused instructions peppered with body-related language (e.g., "Extend your wrist," "Move your elbow closer to your body," "Focus on your diaphragm"; Durham et al., 2009; Porter, Wu, & Partridge, 2010). It has become clear that even minor use of IF language may be sufficient to result in less-than-optimal performance (e.g., Chua et al., 2020; Wulf, Dufek, et al., 2010).

Not only instructors, but performers themselves should be aware of the influences of attentional focus. Often, performers spontaneously focus on their own movements unless they are instructed otherwise (Land et al., 2013; Mornell & Wulf, 2019; Pascua et al., 2015). People's inclination to focus on their movements—perhaps especially when learning a new skill, in evaluative settings or the presence of an audience (e.g., Wallace et al., 2005), or after injury (Gray, 2015)—may be the result of previous instructions they received or simply a reflection of the human tendency to become self-conscious in public or social settings, when errors become obvious, or when performers are concerned about reinjury. Nevertheless, as evidenced in empirical findings synthesized in this study, maintaining an external focus of attention even in challenging situations will facilitate optimal performance.

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(*Appendix follows*)

Appendix

Summary of Study Characteristics

Author(s)	Year	Type of Meta-Analysis	Age Group	Health Status	Skill Level	*N*	Task	Outcome Measure	Hedges' *g*	Standard Error	Risk of Bias
Abdollahipour et al.	2008	Retention	Children	Healthy	Novice	76	Soccer dribbling	Movement time	0.449	0.225	Moderate
		Transfer				76			0.514	0.227	
Abdollahipour et al.	2019 Exp 2	Retention	Adults	Visual impairment	Novice	26	Pedalo riding	Movement time	0.379	0.383	Moderate
		Transfer				26			1.463	0.305	
Abdollahipour & Psotta	2017	Performance	Children	Healthy	Novice	24	Ball catching	Score	0.459	0.211	Moderate
Abdollahipour et al.	2016	Performance	Adults	Healthy	Novice	24	Jumping	Jump height	0.097	0.201	Low
Abdollahipour et al.	2014	Retention	Adults	Healthy	Novice	40	Dart throwing	Accuracy score	−0.076	0.310	Moderate
		Transfer				40			−0.134	0.096	
Abdollahipour et al.	2015	Performance	Children	Healthy	Experienced	24	Jumping	Jump height	0.237	0.204	Moderate
Agar et al.	2016	Retention	Children	Healthy	Novice	48	Puck shooting	Accuracy score	−0.099	0.280	Low
		Transfer				48			−0.297	0.281	
Ahmad et al.	2013	Retention	Adults	Healthy	Novice	44	Volleyball serve	Accuracy score	2.622	0.407	Moderate
An et al.	2013	Retention	Adults	Healthy	Experienced	16	Golf swing	Carry distance	1.120	0.513	Low
Asadi et al.	2015	Performance	Adults	Healthy	Novice	21	Javelin throwing	Throwing distance	0.299	0.219	Low
Ashraf et al.	2017	Performance	Children	Healthy	Novice	20	Jumping	Jump-and-reach height	0.118	0.220	Low
Beck & Almeida	2017	Performance	Older adults	Idiopathic PD	Novice	19	Balance	Postural stability index score	0.054	0.159	Low
Beck et al.	2017	Retention	Older adults	Idiopathic PD	Novice	32	Ground walking	Step length	0.161	0.173	Low
Becker & Smith	2013	Retention	Children	Healthy	Novice	24	Pedalo riding	Movement time	−0.271	0.275	Moderate
			Adults			24			0.352	0.274	
Brocken et al.	2016	Retention	Children	Healthy	Novice	60	Golf putting	Radial error	0.259	0.253	Low
Chiviacowsky et al.	2013	Retention	Children	Intellectual disability	Novice	24	Beanbag tossing	Accuracy score	1.356	0.440	Moderate
		Transfer				24			1.090	0.424	
Chiviacowsky et al.	2010	Retention	Older adults	Healthy	Novice	32	Balance	Time in balance	1.039	0.368	Low
Chow et al.	2014	Retention	Adults	Healthy	Novice	16	Treadmill running	Ankle angle at initial contact phase	−0.245	0.475	Low
Christina & Alpenfels	2014 Exp 1 & 2	Retention	Older adults	Healthy	Experienced	56	Golf swing	Adjusted swing path	0.981	0.279	Low
Coker	2016	Performance	Adults	Healthy	Expert	21	Jumping	Jump distance	0.533	0.229	Moderate
		Distance effect							−0.232	0.217	
Coker	2018	Performance	Children	Healthy	Novice	26	Jumping	Jump distance	0.471	0.204	Moderate
da Silva et al.	2017	Retention	Children	Healthy	Novice	38	Ballet pirouette	Degree of rotation	1.493	0.361	Moderate
		Transfer				38			1.246	0.348	
de Melker Worms et al.	2017	Performance	Older adults	Healthy	Experienced	28	Treadmill walking	Step length	0.066	0.187	Low
Diekfuss et al.	2018	Performance	Adults	Healthy	Novice	8	Balance	Time in mediolateral balance	0.872	0.399	Low
Ducharme & Wu	2015	Performance	Adults	Healthy	Novice	29	Balance	Lateral displacement	0.385	0.190	Low
		EMG				29		Peak EMG of right tibialis	0.140	0.184	
Ducharme et al.	2015	Performance	Adults	Healthy	Novice	21	Jumping	Jump distance	0.308	0.219	Low
Duke et al.	2011	Performance	Adult	Healthy	Novice	12	Piano playing	Inter-onset interval variability	−0.228	0.283	Low
					Expert	4			0.214	0.441	
		Distance effect			Novice	12			0.812	0.324	
			Expert			4			0.374	0.454	
Durham et al.	2014	Performance	Older adult	Stroke	Novice	21	Reach-to-grasp and object manipulation	Movement time	−0.010	0.088	Low
Emanuel et al.	2008	Retention	Children	Healthy	Novice	32	Dart throwing	Radial error	−0.296	0.347	Moderate
			Adult			34			0.369	0.338	
		Transfer	Children			32			−0.435	0.349	
			Adult			34			0.514	0.341	
Fasoli et al.	2002	Performance	Older adult	Healthy	Novice	17	Reach-to-grasp and object manipulation	Movement time	0.539	0.254	Low
				Stroke		16			0.288	0.249	
Flôres et al.	2005	Transfer	Children	Healthy	Novice	54	Pedalo riding	Movement time	0.423	0.189	Moderate
Freudenheim et al.	2010 Exp 1	Performance	Adult	Healthy	Experienced	38	Swimming	Movement time	0.146	0.161	Low
	2010 Exp 2					30			0.184	0.182	
Gredin & Williams	2016	Retention	Children	Healthy	Novice	24	Soccer chipping	Radial error	0.530	0.403	Moderate
		Transfer				24			−0.081	0.157	
Greig & Marchant	2014	Performance	Adult	Healthy	Experienced	25	Elbow flexion	Peak torque	0.215	0.116	Low
		EMG				25		Peak EMG of biceps brachii	1.502	0.171	
Hadler et al.	2014	Retention	Children	Healthy	Novice	30	Tennis serve	Accuracy score	1.034	0.380	Moderate
		Transfer				30			1.279	0.392	
Halperin et al.	2017	Performance	Adult	Healthy	Experienced	8	Punching	Velocity	0.236	0.339	Low

Appendix (*Continued*)

Author(s)	Year	Type of Meta-Analysis	Age Group	Health Status	Skill Level	*N*	Task	Outcome Measure	Hedges' *g*	Standard Error	Risk of Bias
					Expert	7			0.102	0.355	
Halperin, Hughes, et al.	2016	Performance	Adult	Healthy	Experienced	28	Elbow flexion and jumping	Mean force and jump height	0.240	0.134	Low
		EMG				28	Elbow flexion	Normalized EMG of biceps brachii	−0.075	0.187	
Halperin, Williams, et al.	2016	Performance	Adult	Healthy	Novice	18	Midthigh pull	Peak force	0.323	0.237	Low
Hebert & Williams	2017	Performance	Adult	Healthy	Novice	27	Jumping	Jump distance	0.154	0.191	Moderate
Hill et al.	2017	Performance	Adult	Healthy	Experienced	30	Treadmill running	Oxygen consumption	0.150	0.181	Low
Hosseiny et al.	2014	Performance	Adult	Healthy	Expert	10	Air pistol shooting	Accuracy score	1.889	0.521	Low
Huang et al.	2014	Performance	Adult	Healthy	Novice	12	Balance	Angular deviation	0.767	0.320	Low
Ille et al.	2013	Performance	Adult	Healthy	Novice	8	Sprinting	Movement time	1.040	0.423	Low
					Expert	8			0.945	0.409	
Jackson & Holmes	2011	Retention	Adult	Healthy	Novice	18	Balance	Time in balance	0.131	0.321	Low
Jazaeri et al.	2018	Performance	Older adult	Healthy	Novice	17	Balance	Center of pressure velocity	1.004	0.159	Low
				Idiopathic PD		34			0.347	0.173	
Kal et al.	2013	Performance	Adult	Healthy	Novice	30	Cyclic single-leg extension-flexion	Movement time per cycle	0.199	0.182	Low
		EMG				30		Mean EMG of rectus femoris	−0.112	0.181	
Kalkhoran & Shariati	2014	Transfer	Children	Healthy	Novice	30	Basketball dribbling	Movement time	1.454	0.292	Moderate
Kearney	2015	Performance	Adult	Healthy	Novice	18	Golf putting	Accuracy score	−0.101	0.231	Low
		Distance effect				18			0.873	0.273	
Kim, Hinojosa, et al.	2017	Retention	Adult	Stroke	Novice	30	Arm movement	FMA-UE score	0.016	0.355	Low
Klostermann et al.	2014	Performance	Adult	Healthy	Expert	24	Golf putting	Radial error	1.209	0.266	Low
Koufou et al.	2013	Retention	Children	Healthy	Novice	20	Forward tuck roll	Movement quality score	0.791	0.446	Moderate
Kuhn et al.	2018 Exp 1 & 2	Performance	Adult	Healthy	Novice	26	Finger flexion	Mean force and reaction time	0.211	0.192	Low
	2018 Exp 1	EMG				14		RMS EMG of abductor pollicis brevis	0.275	0.265	
Kuhn et al.	2017	Performance	Adult	Healthy	Novice	14	Finger abduction	Time to task failure	0.607	0.284	Low
		EMG				10		EMG suppression of right first dorsal interosseous	1.628	0.474	
Land et al.	2014	Retention	Adult	Healthy	Novice	20	Golf putting	Radial error	1.695	0.505	Low
Landers et al.	2016	Transfer	Adult	Idiopathic PD	Experienced	21	Balance	Berg Balance Scale score	−0.013	0.297	Low
Landers et al.	2005	Performance	Older adult	Idiopathic PD	Novice	22	Balance	Equilibrium score	0.660	0.138	Low
Laufer et al.	2007	Retention	Adult	Ankle sprain	Novice	40	Balance	Overall Stability Index	0.198	0.220	Low
Lawrence et al.	2011	Retention	Adult	Healthy	Novice	20	Gymnastics routine	Movement form score	0.948	0.454	Low
		Transfer				20			0.937	0.453	
Lisman & Sadagopan	2013	Performance	Adult	Healthy	Novice	20	Speech	Production time	1.205	0.290	Low
Lohse et al.	2014	Performance	Adult	Healthy	Novice	15	Dart throwing	Absolute error	0.791	0.290	Low
		Distance effect				15			5.248	0.991	
Lohse & Sherwood	2011 Exp 1	Performance	Adult	Healthy	Novice	20	Wall-sit	Time to task failure	0.223	0.222	Low
Lohse & Sherwood	2012 Exp 1 & 2	Performance	Adult	Healthy	Novice	24	Force production (plantar flexion)	Absolute error and time to task failure	0.273	0.142	Low
		EMG				24	Cocontraction ratio of tibialis to soleus		0.419	0.147	
Lohse et al.	2010	Performance	Adult	Healthy	Novice	12	Dart throwing	Absolute error	1.274	0.381	Low
		EMG				12		Integrated EMG of triceps	1.370	0.395	
Lohse et al.	2011	Performance	Adult	Healthy	Novice	12	Force production (plantar flexion)	Absolute error	2.587	0.597	Low
		EMG				12	Cocontraction ratio of tibialis to soleus		1.516	0.416	
Makaruk et al.	2012	Transfer	Children	Healthy	Experienced	24	Jumping	Jump distance and height	0.651	0.237	Low
Makaruk et al.	2015	Performance	Older adult	Healthy	Experienced	23	Ergometer cycling	Maximum power	0.303	0.210	Low
Makaruk et al.	2013	Performance	Adult	Healthy	Experienced	30	Shot put	Throw distance	0.274	0.130	Low
Marchant, Carnegie, et al.	2018	Performance	Adult	Healthy	Novice	26	Golf putting	Radial error	0.362	0.142	Low
Marchant, Clough, et al.	2009	Performance	Adult	Healthy	Novice	72	Dart throwing	Absolute error	0.336	0.085	Low
Marchant & Greig	2017	Performance	Adult	Healthy	Experienced	20	Force production (knee extension)	Peak torque	0.012	0.219	Low
		EMG				20	Integrated EMG of vastus medialis oblique		0.279	0.224	
Marchant et al.	2011	Performance	Adult	Healthy	Experienced	40	Bench press and back squat	Number of repetitions to failure	0.752	0.155	Moderate
Marchant, Greig, et al.	2009	Performance	Adult	Healthy	Experienced	25	Elbow flexion	Peak torque	2.962	0.463	Low
		EMG				25			1.705	0.311	

Appendix (*Continued*)

Author(s)	Year	Type of Meta-Analysis	Age Group	Health Status	Skill Level	*N*	Task	Outcome Measure	Hedges' *g*	Standard Error	Risk of Bias
								Integrated EMG of biceps brachii			
Marchant, Griffiths, et al.	2018	Performance	Children	Healthy	Novice	98	Jumping	Jump distance	0.122	0.101	Moderate
		Distance effect				54			0.101	0.135	
Maurer & Munzert	2013 Exp 1	Performance	Children	Healthy	Expert	23	Basketball free throw	Success rate	−0.523	0.219	Low
	2013 Exp 2		Adult		Novice	14	Golf putting		−0.554	0.280	
McKay & Wulf	2012	Distance effect	Adult	Healthy	Novice	36	Dart throwing	Accuracy score	0.417	0.172	Moderate
McNevin et al.	2003	Retention	Adult	Healthy	Novice	20	Balance	Angular deviation	0.430	0.434	Low
McNevin et al.	2013	Performance	Adult	Healthy	Novice	12	Supra-postural manual tracking	Time on target	0.118	0.199	Low
			Older adult	Cardiac condition		12			0.532	0.212	
Mornell & Wulf	2019 Exp 1 & 2	Performance	Adult	Healthy	Novice	41	Music production	Musicality score	0.532	0.164	Low
Mullen et al.	2012	Retention	Adult	Healthy	Novice	16	Simulation driving	Lap time	1.161	0.515	Low
Nadzalan et al.	2015	Performance	Adult	Healthy	Experienced	30	Bench press	Number of repetitions to failure	2.488	0.319	Low
Neumann & Piercy	2013	Performance	Adult	Healthy	Novice	21	Treadmill running	Oxygen consumption	−0.402	0.223	Low
Oki et al.	2018	Performance	Adult	Healthy	Expert	12	Baseball throwing	Throw distance	1.699	0.445	Low
Palmer et al.	2017	Performance	Children	Healthy	Novice	44	Ball control	Score	0.442	0.157	Low
Parr & Button	2009	Retention	Children	Healthy	Novice	12	Rowing	Apex to lock distance of blade	1.585	0.623	Low
		Transfer				12			1.814	0.649	
Pelleck & Passmore	2017	Performance	Adult	Healthy	Novice	11	Golf putting	Radial error	−0.113	0.206	Low
					Expert	13			0.011	0.195	
		EMG			Novice	11		RMS EMG of left extensor carpi radialis	0.037	0.205	
					Expert	13			0.075	0.190	
Perkins-Ceccato et al.	2003	Performance	Not reported	Healthy	Experienced	10	Golf pitch shot	Radial error	−0.183	0.306	Low
					Expert	10			0.056	0.303	
Perreault & French	2015	Retention	Children	Healthy	Novice	28	Modified basketball free throw	Accuracy score	2.207	0.471	Low
Polskaia et al.	2015	Performance	Adult	Healthy	Novice	20	Postural control	Sway area	0.052	0.219	Low
Porter & Anton	2011	Performance	Older adult	Cancer	Novice	5	Manual tracking	Contact time	0.749	0.468	Low
Porter et al.	2013	Performance	Adult	Healthy	Expert	38	Jumping	Jump distance	0.460	0.169	Moderate
		Distance effect				38			0.335	0.165	
Porter et al.	2012	Distance effect	Adult	Healthy	Experienced	35	Jumping	Jump distance	0.191	0.169	Moderate
Porter, Nolan, et al.	2010	Performance	Adult	Healthy	Novice	20	Sprinting	Movement time	2.639	0.471	Low
Porter & Sims	2013	Performance	Adult	Healthy	Expert	9	Sprinting	Movement time	0.000	0.317	Low
Porter et al.	2015	Performance	Adult	Healthy	Experienced	84	Sprinting	Movement time	0.223	0.110	Low
Querfurth et al.	2016	Performance	Adult	Healthy	Experienced	20	Dart throwing	Radial error	0.129	0.220	Low
Raisbeck & Yamada	2019	Distance effect	Adult	Healthy	Novice	24	Jumping	Jump height	0.291	0.205	Low
Richer et al.	2017	Performance	Children	Healthy	Novice	16	Balance	Sway area	−0.123	0.245	Low
Rossettini et al.	2017	Performance	Adult	Healthy	Novice	10	Finger sequence tapping	Number of errors	4.221	0.991	Low
Saemi et al.	2016	Performance	Adult	Healthy	Expert	11	Basketball free throw	Accuracy score	1.492	0.304	Low
Saemi et al.	2013	Retention	Children	ADHD	Novice	20	Tennis ball throwing	Accuracy score	1.281	0.474	Moderate
Samsudin & Low	2017	Retention	Children	ASD	Novice	10	Boule throwing	Radial error	4.428	1.143	Low
Schücker, Anheier et al.	2013	Performance	Adult	Healthy	Expert	20	Treadmill running	Oxygen consumption	0.292	0.224	Low
Schücker, Fleddermann et al.	2016	Performance	Adult	Healthy	Expert	24	Ergometer cycling	Oxygen consumption	0.054	0.201	Low
Schücker et al.	2009	Performance	Adult	Healthy	Expert	24	Treadmill running	Oxygen consumption	0.345	0.207	Low
Schücker et al.	2015	Performance	Adult	Healthy	Expert	18	Ergometer rowing	Oxygen consumption	0.157	0.232	Low
Schücker, Schmeing, et al.	2016	Performance	Adult	Healthy	Novice	30	Treadmill running	Oxygen consumption	0.329	0.185	Low
Schutts et al.	2017	Performance	Adult	Healthy	Expert	12	Snatch	Barbell-cervical-hip angle at maximum height	0.154	0.280	Low
Shafizadeh, Platt & Bahram	2013	Retention	Adult	Healthy	Novice	24	Dart throwing	Accuracy score	0.536	0.402	Moderate
		Transfer				24			0.746	0.409	
Shafizadeh, Platt & Mohammadi	2013	Performance	Adult	Multiple sclerosis	Novice	12	Treadmill walking	Step length	0.753	0.318	Moderate
Shea & Wulf	1999	Retention	Adult	Healthy	Novice	32	Balance	Angular deviation	0.768	0.350	Low
Sherwood et al.	2014 Exp 1 & 2	Performance	Adult	Healthy	Novice	48	Dart throwing	Radial error	2.320	0.276	Low
Stambaugh	2017	Performance	Adult	Healthy	Novice	15	Playing of musical instrument	Pitch error	0.120	0.252	Low
					Experienced	15			−0.199	0.254	
		Distance effect			Novice	15			−0.461	0.265	
					Experienced	15			0.017	0.251	
Stoate & Wulf	2011	Performance	Children	Healthy	Expert	30	Swimming	Movement time	0.224	0.183	Low
Totsika & Wulf	2003	Transfer	Adult	Healthy	Novice	22	Pedalo riding	Movement time	0.862	0.249	Moderate
Tse	2017	Retention	Children	ASD	Novice	44	Beanbag throwing	Radial error	−1.782	0.352	Moderate
		Transfer				44			−1.136	0.320	

Appendix (*Continued*)

Author(s)	Year	Type of Meta-Analysis	Age Group	Health Status	Skill Level	*N*	Task	Outcome Measure	Hedges' *g*	Standard Error	Risk of Bias
Tse & van Ginneken	2017	Retention	Children	Healthy	Novice	40	Dart throwing	Radial error	0.155	0.341	Low
Tsetseli et al.	2016	Retention	Children	Healthy	Experienced	40	Tennis match	Score	0.507	0.315	Moderate
Tsetseli et al.	2018	Retention	Children	Healthy	Experienced	44	Tennis serve	Score	2.259	0.382	Moderate
Uehara et al.	2008	Retention	Adult	Healthy	Novice	12	Soccer chipping	Radial error	−0.294	0.536	Moderate
Vance et al.	2004 Exp 1 & 2	EMG	Adult	Healthy	Experienced	24	Biceps curls	Integrated EMG of biceps brachii	1.420	0.286	Low
Welling et al.	2016	Retention	Adult	Healthy	Novice	20	Jumping	Jump height	0.090	0.429	Low
Winkelman et al.	2017 Exp 1 & 2	Performance	Adult	Healthy	Experienced	16	Sprinting	Movement time	0.221	0.247	Low
					Expert	13			−0.075	0.269	Low
Wu et al.	2012	Performance	Adult	Healthy	Novice	21	Jumping	Jump distance	0.324	0.220	Moderate
Wulf et al.	2008	Performance	Adult	Healthy	Expert	12	Balance	Mean power frequency	−0.022	0.279	Low
Wulf, Chiviacowsky, et al.	2010	Retention	Children	Healthy	Novice	48	Soccer throw-in	Movement form score	0.421	0.286	Low
		Transfer				48			0.313	0.285	
Wulf & Dufek	2009	Performance	Adult	Healthy	Novice	10	Jumping	Center of mass displacement	0.555	0.327	Low
Wulf, Dufek et al.	2010	Performance	Adult	Healthy	Novice	8	Jumping	Jump-and-reach height	0.150	0.336	Low
		EMG				8		RMSE EMG of 5 leg muscles	1.715	0.544	
Wulf et al.	1998 Exp 1 & 2	Retention	Adult	Healthy	Novice	38	Slalom-ski simulation, balance	Movement amplitude and angular deviation	1.371	0.351	Low
Wulf et al.	2009	Performance	Older adult	Idiopathic PD	Novice	14	Balance	RMSE center of pressure	0.435	0.272	Low
Wulf et al.	1999	Retention	Adult	Healthy	Novice	22	Golf pitch shot	Accuracy score	1.490	0.468	Moderate
Wulf et al.	2002 Exp 1 & 2	Retention	Adult	Healthy	Experienced	100	Volleyball serve, soccer lofted pass	Accuracy score	1.281	0.217	Moderate
Wulf et al.	2001	Retention	Adult	Healthy	Novice	28	Balance	Angular deviation	2.007	0.455	Low
Wulf & Su	2007 Exp 1	Retention	Adult	Healthy	Novice	20	Golf pitch shot	Accuracy score	0.358	0.432	Low
	2007 Exp 2	Performance			Expert	6			0.669	0.423	
Wulf, Töllner, et al.	2007 Exp 1 & 2	Performance	Adult	Healthy	Novice	42	Balance	RMSE center of pressure	0.092	0.108	Low
Wulf, Wächter, et al.	2003	Retention	Children	Healthy	Novice	40	Soccer straight pass	Accuracy	0.338	0.316	Low
		Transfer				40			0.323	0.308	
Wulf, Weigelt, et al.	2003	Retention	Adult	Healthy	Novice	38	Balance	Angular deviation	1.688	0.367	Low
		Transfer				38			1.410	0.351	
Wulf, Zachry, et al.	2007 Exp 1 & 2	Performance	Adult	Healthy	Novice	22	Jumping	Jump-and-reach height and center of mass displacement	0.305	0.211	Low
Yogev-Seligmann et al.	2017	Performance	Older adult	Healthy	Experienced	20	Walking	Step length	−0.047	0.219	Low
Zachry et al.	2005	Performance	Adult	Healthy	Experienced	14	Basketball free throw	Accuracy score	0.462	0.274	Moderate
		EMG				14		RMS EMG of triceps	1.310	0.359	
Zarghami et al.	2012	Performance	Adult	Healthy	Experienced	20	Discus throwing	Distance	0.491	0.232	Low
Zentgraf & Munzert	2009	Retention	Adult	Healthy	Novice	46	Juggling	Rate of correct trials	0.181	0.290	Low
Ziv & Lidor	2015	Retention	Adult	Healthy	Novice	48	Golf putting	Radial error	0.068	0.284	Low
		Transfer				48			−0.123	0.284	
Ziv et al.	2013	Performance	Adult	Healthy	Experienced	24	Treadmill running	Oxygen consumption	−0.039	0.201	Low

Note. ADHD = attention deficit hyperactivity disorder; ASD = autism spectrum disorder; EMG = electromyographic; FMA-UE = Fugl-Meyer Assessment – Upper Extremity; PD = Parkinson disease; RMS = root-mean-square; RMSE = root-mean-square-error.

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