

Review

## Should Rehabilitation Specialists Use External Focus Instructions When Motor Learning Is Fostered? A Systematic Review

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**Abstract:** According to the Constrained Action Hypothesis, motor learning is believed to be more efficient when an external focus (EF) of motor control is given to the performer instead of an internal focus (IF) of motor control. This systematic review investigated whether findings of studies focusing on the Constrained Action Hypothesis may be transferred to rehabilitation settings by assessing the methodological quality and risk of bias (ROB) of available randomized controlled trials (RCTs). Of the 18 selected reports representing 20 RCTs, the methodological quality was rather low, and the majority of the reports appeared to have a high ROB. The 18 reports included 68 patients tested in a rehabilitation setting and 725 healthy participants. The time scale of the motor learning processes presented in the selected articles was heterogenic. The results of this systematic review indicate that the assumption that an external focus of control is to be preferred during motor learning processes is not sufficiently substantiated. The level of available evidence is not large enough to warrant transfer to patient populations (including children and the elderly) and raises doubts about research with healthy individuals. This implies that based on the methodology used so far, there seems to be insufficient evidence for the superiority of an external focus of control, neither in healthy individuals nor in clinical populations. The relationship between EF instructions and motor learning research and its

effect in both patient rehabilitation settings and healthy populations requires further exploration. Future adequately powered studies with low ROB and with rehabilitation populations that are followed over extended time periods should, therefore, be performed to substantiate or refute the assumption of the superiority of an EF in motor learning.

**Keywords:** feedback; instruction; motor control; patients; sport; training; intervention

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## 1. Introduction

Motor learning can be defined as: “a set of processes associated with practice or experience, leading to relatively permanent changes in the capability for movement” [1]. Motor learning research, with its focus on discovering the laws and principles underlying the acquisition of motor skills, has had little impact on clinical applications, *i.e.*, in physical and occupational therapy [2]. At a USA-held workshop sponsored by the National Center for Medical Rehabilitation Research, the argument was made that even though “learning is central to medical rehabilitation...most therapists' use of learning principles is intuitive and the result of their personal clinical experience” [3]. For many complex motor tasks, where the learner is required to coordinate and control the many degrees of freedom associated with performing the task; however, the instructions delivered by a coach or therapist can theoretically simplify a potentially daunting task [4].

Instructions or feedback that direct the performer’s attention to the effects that her or his movements have on the environment (external focus, EF) have been stated to lead to more effective learning than directing attention to the movements themselves (internal focus, IF). Importantly, EF benefits have not only been found relative to IF conditions, but also relative to control conditions [5,6]. That is, including an EF allegedly results in performance advantages, while IF conditions and control conditions with no specific focus instructions produce similar and less effective motor performance or learning of new motor skills.

In a review on motor skill learning, the idea of a decrease in attention with practice is described [7]. This idea can be followed back to the theories of James from 1890 [8]. James refers to the development of automaticity during the learning of a new motor task. He also postulated that during the performance of an unfamiliar task, the actor uses the conscious mode, and by gaining experience in the task, the unconscious mode emerges and, in turn, the conscious mode becomes redundant [7]. This gain in experience can be achieved over different time scales [9]. The timing of motor skill learning should, therefore, be assessed at different stages: (1) a fast learning stage in which the improvements take place within a single training session and (2) a slow learning stage in which the gains are achieved over multiple sessions of practice over longer time periods; e.g. weeks or months [9]. These different stages are corroborated by several clinical research groups and involve different neural substrates [10–12].

It is generally accepted that complex motor skills require a huge amount of practice. The Olympic brain is developed by tedious repetitions over years until the movement is perfect [13]. This accounts for the healthy population. However, motor skill learning is not only the domain of sports teachers and

scientists, but also therapists in rehabilitation settings (occupational and physical therapists) are working in the field of improvement of motor performance. In the field of rehabilitation, the first stage of motor learning may be different, as it may take a period of weeks (or months) to teach a new motor skill to a patient group. Patients have to learn (or relearn) motor skills over several weeks, and after this extended period of motor learning, they are far from the phase of automaticity. It may even be the case that in the therapeutic domain, the rules of automaticity are very different from the healthy population [14].

Wulf and colleagues formulated the “constrained action hypothesis” in order to explain their consistent findings of impaired learning under internal focus conditions [15]. However, it has not been systematically investigated whether the “constrained action hypothesis” [15] may be generalized to rehabilitation settings where patient re-education takes place. The field of disability and rehabilitation (D&R) faces the challenge of identifying and applying evidence to its practice. Guidelines and recommendations regarding clinical and community practice in D&R should be based on the best available evidence. The standards and methods used to select that evidence should address research quality, the needs and values of people with disabilities and the applicability to practice [16].

Narrative reviews that are focused on the differences between EF and IF instructions are contradictory regarding their conclusions about the practical relevance [17,18]. Furthermore, there is some inconsistency in the arguments that are used to explain the effect or lack of effect of EF instructions. Visual feedback, for example, is proposed to promote the effects of an EF [19]; however, it also may explain the lack of an EF effect [20]. We, therefore, performed a systematic review on EF and IF instruction with the aim of clarifying the relationship between the type of instruction and the effects on (fast and slow) motor skill learning in both healthy subjects and patients. The following research question guided this systematic review: *“Is a speedier acquisition of a new motor skill and a better performance in expert motor skills positively related to specific forms of instruction (internal focus versus external focus instructions) that a trainer or therapist uses to assist learning of these skills?”*

## 2. Methods

### 2.1. Data Sources and Searches

We developed the search strategy in collaboration with a librarian (MG) from the Medical Library of the University of Zurich. The search period covered all years from the inception to April, 2013, and included Medline, the Physiotherapy Evidence Database (PEDro), CINAHL, SCOPUS and SPOLIT/SPOWIS.

Searches were undertaken using MeSH headings and text words, as suitable. The search strategy used in the databases is shown in Appendix 1.

Furthermore, the bibliographies of all eligible articles and related reviews, as well as recent conference proceedings, were checked through hand searching. To ensure the clarity and transparency of reporting, the PRISMA guidelines were followed [21]. Randomized controlled trials (RCT) are the most rigorous way of determining whether a cause-effect relation exists between treatment and outcome [22] and were, for this reason, the only study type included.

## 2.2. Criteria for Considering Studies for This Review

Two reviewers (TK and EDB) assessed the studies independently, using the following inclusion criteria: 1. the study was a randomized controlled trial published in English language in peer reviewed journals or doctoral theses; 2. studies should compare an external focus motor learning task against an internal focus motor learning task; 3. studies with healthy individuals (children and adults) and clinical populations were included; 4. outcomes reflecting the motor learning constructs of external and internal focus of motor control were reported.

Controlled clinical trials, quasi-randomized trials, one group studies, single case studies and feasibility studies were excluded. Disagreements were resolved by consensus. If no consensus was reached, the third author (RK) was consulted to decide.

To facilitate comparison between studies, the following data were extracted: (a) design and settings; (b) intervention components, including sample size and length of the intervention; (c) effectiveness of the intervention immediately after intervention and at subsequent follow-up (e.g., retention phase). Tables 1 and 2 give a description of the retrieved data.

## 2.3. Data Collection and Quality Assessment

Two reviewers (RK and EDB) independently applied the Cochrane Collaboration's tool for assessing risk of bias (ROB) to assess the risk of over- or under-estimating the effects of an intervention [23]. Nine items, with each having three rating categories, were scored and divided into six domains of bias (Figures 2 and 3) [23]: (1) low ROB, (2) unclear ROB and (3) high ROB. Rating (1) is unlikely to alter the results significantly, (2) raises some doubt about the results and (3) seriously weakens confidence in the results. With insufficient information on an item, the score given was "high risk".

The arbitration of a third reviewer (TK) was used in the event of any disagreement between the reviewers (EDB, RK) for both ratings.

## 3. Analysis

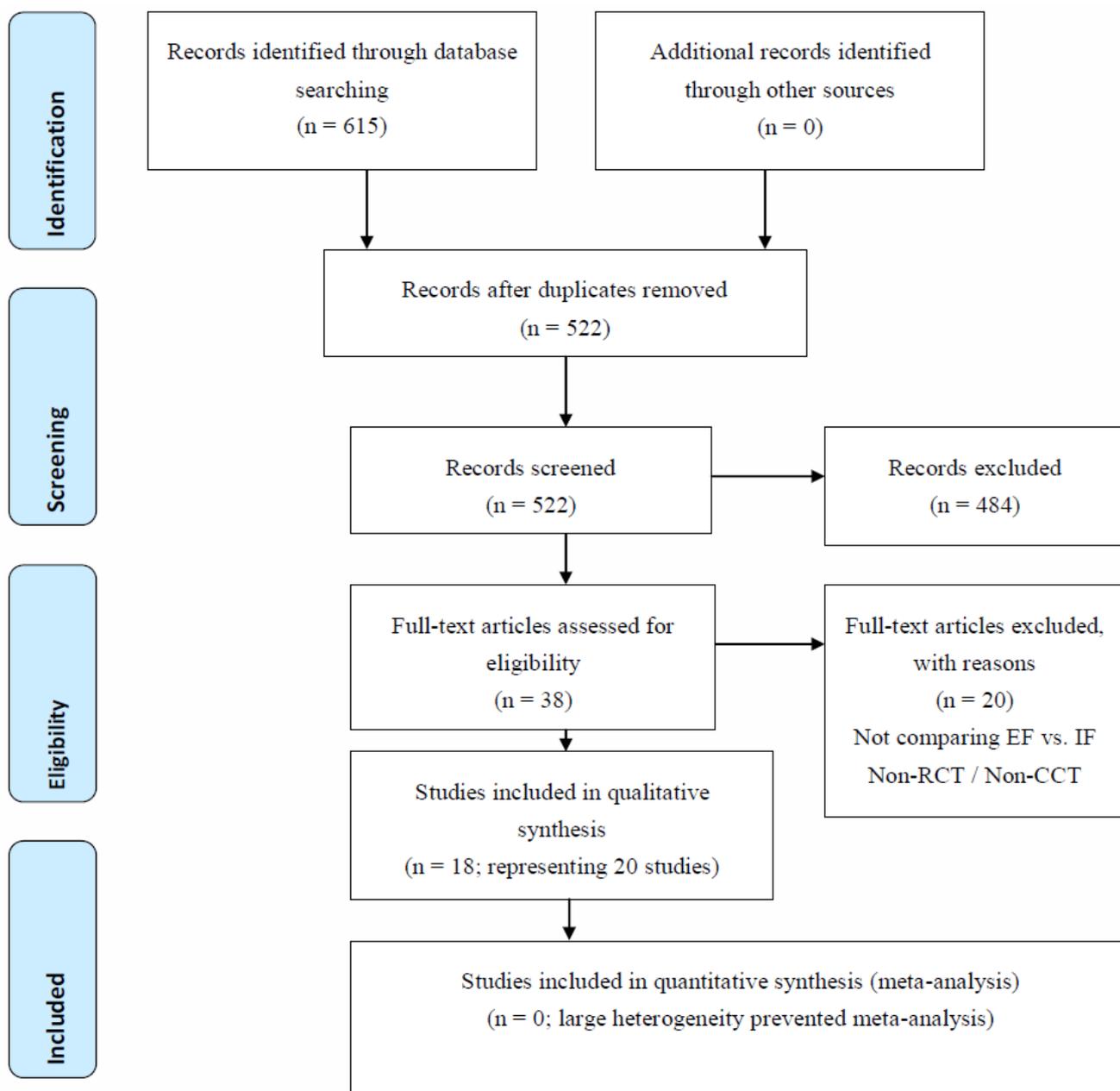
The 95% confidence intervals (CIs) were used to describe the effect of each intervention on the target outcomes (if available). When there were repeated measures over the course of the study, the first time point after intervention was selected, particularly if the primary time point was not clear. The selection of the first time point has several advantages. It helps to differentiate between effects due to natural recovery and those due to intervention in the case of treatment. The intrusion of the effect of confounding variables, such as co-interventions, is minimized, and the ability to pool all available data from all studies at this time point is enhanced [24].

## 4. Results

From the original 522 articles, only 20 RCTs written down in 18 different reports (articles) met our inclusion criteria and were integrated in the final analysis. Figure 1 represents the flowchart of the

identified and, finally, selected studies. The majority of the reports were shown to have a high ROB (Figures 2 and 3). Two reports described the same intervention [25,26], leading us to regard it as one single study in the description (Tables 1 and 2). Two papers presented both of two experiments, which were treated as two separate studies [27,28]. This left us with 18 different reports describing 20 RCTs.

**Figure 1.** PRISMA 2009 Flow Diagram [51]. EF, external focus; IF, internal focus; RCT, randomized controlled trial; CCT, controlled clinical trial.

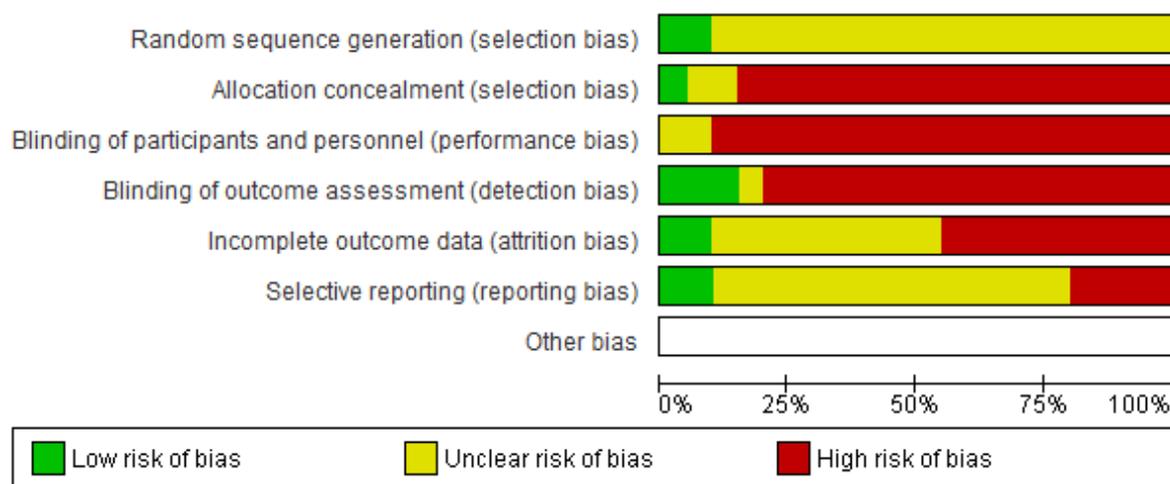


## 5. Methodological Quality Assessed with the Risk of Bias

Both reviewers (EDB and RK) solved disagreements by discussion based on the report and guidelines of Higgins and Altman [23], and thus, arbitration of the third reviewer (TK) was not needed.

Based on the ROB, it appears that the majority of the included studies either raise some doubt about their results or there is an apparent seriously weakened confidence in the results. The results of the ROB are summarized in Figures 2 and 3. None of the studies were free from bias. All eighteen studies (20 reports) were described as RCTs, but only in two papers, the method of random sequence was described clearly [28] (experiment 2) and [29]. Allocation concealment was adequately reported in one study [29] and unclear in the remaining studies. None of the studies reported the blinding of both the patients and the study personnel. Three studies described the blinding of the test administrators [25,30,31]. In two studies, outcome data were complete or missing data were adequately explained and, thus, unlikely to cause bias [29,31]. In two studies, details on dropouts were provided and/or an intention to treat analysis was used [29,30].

**Figure 2.** Risk of bias (ROB) graph: review authors' judgments about each ROB item presented as percentages across all included studies.



## 6. Summary of the Studies

The 20 RCTs (written down in 18 different reports) in this systematic review included 725 participants. One trial reported the effect of EF and IF on stroke patients [30]. Two reports from one trial [25,26] reported the effect of IF and EF on 40 and 36 ankle sprain patients, respectively. One trial reported the effect on the elderly [29] and one in children and adults [32]. The remaining studies used students [15,19,28,33-39], (young) adults [27,40] and gymnasts [31].

IF instruction significantly improved motor function in stroke patients [30] and in children collectively [32]. EF instruction significantly improved motor function in healthy students and adults [15,27,28,32,33,36-40].

The trials of Laufer *et al.* [26], Rotem-Lehrer *et al.* [25], Koedijker *et al.* [34] and de Bruin *et al.* [29] did not yield significant differences between IF and EF instruction groups.

**Figure 3.** ROB summary: review authors' judgments about each ROB item for each included study.

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Cirstea	?	-	-	+	?	+	
de Bruin	+	+	-	-	+	+	
Emanuel	?	-	-	-	-	?	
Freedman	?	-	-	-	?	?	
Jackson	?	-	-	-	?	?	
Koedijker	?	-	-	-	?	-	
Laufer	?	-	-	?	?	-	
Lawrence	?	-	-	+	+	?	
Makaruk 2013	?	?	?	-	?	?	
Poolton (Exp. 1)	?	-	-	-	?	?	
Poolton (Exp. 2)	?	-	-	-	?	?	
Porter	?	-	-	-	?	?	
Radlo	?	-	-	-	-	-	
Rotem-Lehrer	?	-	?	+	-	-	
Shea & Wulf 1999	?	?	-	-	-	?	
Wulf & Höss (Exp. 1)	?	-	-	-	-	?	
Wulf & Höss (Exp. 2)	+	-	-	-	-	?	
Wulf & Lauterbach	?	-	-	-	-	?	
Wulf & McConnel	?	-	-	-	-	?	
Wulf & McNevin	?	-	-	-	-	?	

Motor learning took place in two studies [29,32], in which 60 children or elderly (over seventy years of age) participated. In the study of Emanuel *et al.* [32], on the acuity of dart throws, there was an age effect for the internal and external focus of motor control conditions: the adults improved significantly on the EF of control condition, whereas the children profited more from the IF. In the study on the elderly who trained on dynamic balance, there was no significant difference between the IF and EF condition following a six-weeks training intervention for postural balance [29].

In 13 articles, mainly young, most likely intelligent (as university students) males were studied. In two articles, there was no significant difference between the IF and EF condition [31,34]. In the article of Lawrence [31], the focus was on healthy gymnasts. Gymnasts who learn gymnastic routines for which the form is important and for whom there is rarely output in the form of a target to be hit (no ball or stick involved), it seems clear that an EF of motor control might not be important. In the Koedijker *et al.* report [34], it turned out that the amount of rules to be learnt by the subjects were more decisive for motor learning than the direction of the focus of motor control. In both studies, there was no significant difference between the EF and IF conditions.

For all the other remaining ten articles, the EF condition was better than the IF condition, as stated by the authors. In these ten articles, however, motor learning was measured at different time scales (Table 2). The results imply, therefore, that when performance changes are measured immediately after the learning phase, rather, the beginning of motor learning (the acquisition) was measured instead of the phase of automaticity [12,41]. Whether it is better in this phase to have an IF or EF of motor control seems very much dependent on the task. One study described the effects of nine-weeks training [35] and assessed the effects with a  $3 \times 2$ -ANOVA. The ANOVA reported time effects, but no interaction effects for the three groups, implying similar performance development for all three groups independent from instructions given. As stated above for the gymnastic routines, in motor tasks for which the esthetic part (or the position of the joints, in the case of patients) is more important, an IF may be more advantageous. Research into the effects of EF conditions, furthermore, obviously predominantly takes place on a population that is rather young (student population), urban and intelligent.

## 7. Quantitative Analyses

Given that many of the trials reviewed used small sample sizes, were heterogeneous in the types of IF and EF motor learning programs investigated and were different in the periods of follow-up, we considered statistical pooling of data across trials [42]. However, this was not feasible, because of the variety in outcomes assessed.

## 8. Discussion

This systematic review aimed at clarifying the relationship between the type of instruction and the effects on (fast and slow) motor skill learning in both healthy subjects and patients. Based on our findings, the answer to our research question “*Is a speedier acquisition of a new motor skill and a better performance in expert motor skills positively related to specific forms of instruction (internal focus versus external focus instructions) that a trainer or therapist uses to assist learning of these*

*skills?*” must be “no” or, at best, “this cannot be answered yet”. The methodological quality of the included reports was rather, low and the majority of the reports were shown to have a high ROB. The latter finding leads to the risk of over- or under-estimating the effects of the assessed interventions [23]. The most commonly observed problems were concealment of treatment allocation, blinding of the participants and personnel and failure to employ an intention-to-treat data analysis strategy.

One of the results of our review was the inclusion of different age groups of the population (young children, young and older adults) with different health backgrounds (healthy to patients) that were all studied under IF and EF instructions. This is because we wanted to clarify the relationship between the type of instruction and the effects on (fast and slow) motor skill learning in general. This approach revealed that there might be both age effects [32] and health status effects that might explain whether an EF is more effective or not when motor learning is expected to take place. The extension of research findings and conclusions from a study conducted on a sample population to the population at large requires data on large populations, because the larger the sample population, the more one can generalize the results. Given that we were only able to find studies describing 68 patients and 725 healthy participants, the answer to the question of whether an EF is favorable for motor learning in various populations and has generalizability to the population at large is still open.

How motor processes are affected by internal *versus* external foci is explained through the “constrained action hypothesis”. According to this view, focusing attention on the movement effect promotes an automatic mode of movement control [15]. It is assumed that through the adoption of an EF, unconscious, fast and reflexive processes are enabled to control the movements. Evidence in support of the “constrained action hypothesis” view is related to attention capacity, the frequency of movement adjustments and the degree of muscular activity observed under different focus conditions. Motor learning effectiveness in which IF was compared with EF was investigated in 18 studies (articles); however, only two studies [25,26,30] dealt with a patient population (one study described in two different articles). Counting all subjects who participated in the studies of this systematic review together (N = 725), it turned out that 657 healthy subjects were involved and 68 patients. As the effectiveness of motor learning for those who are not healthy might be more important, we will begin discussing the latter.

Immediately after training, it turned out that the stroke patients who learned to perform pointing movements with the affected arm with an IF were significantly better post-training on two of three measured outcomes [30], as compared to the EF condition. After four weeks, both groups (IF and EF) were equal in their improvement on a retention test. The second study with patients was on subjects receiving training after an ankle sprain [25,26]. Although the authors of both articles state that an EF is better than an IF condition, the presented results are elusive. There was no main effect of group (EF *versus* IF) in neither of the two reports. This was neither the case after the acquisition phase [25] nor after the retention phase [26]; however, there was an interaction with time. The interaction indicated that EF is more advantageous on two of the three parameters in the study by Laufer *et al.* [26] and on all three parameters in the study by Rotem-Lehrer [25], as the slope of improvement was steeper in the IF condition. It was not explained, however, why four subjects, initially recruited, were omitted from the analysis in the Laufer study, why there was no correction for baseline differences between the groups (the EF group started at a higher base level) and why the data of the same subjects were presented twice.

When evaluating the validity of a study, it is important to consider both the clinical and statistical significance of the findings [43]. Studies that claim clinical relevance may lack sufficient statistical significance to make meaningful statements or, conversely, may lack practicality, despite showing a statistically significant difference in treatment options. Researchers and clinicians should, therefore, not focus on small *p*-values alone to decide whether a treatment is clinically useful; it is necessary to also consider the magnitude(s) of treatment differences and the power of the study [43]. Striking in this context is the observation that the majority of the included reports of this systematic review do not report mean values with their corresponding standard deviations for the outcomes. This prevents determining the effect sizes attributable to EF and IF instructions in the interventions. In those cases where mean and standard deviation values are given and effect sizes may be determined, the between groups comparisons show no or small magnitude(s) of treatment differences. One study that reports moderate effect sizes for the physical performance measures used a  $3 \times 2$ -ANOVA for data analysis. Although the ANOVA reported no interaction effects for the three groups, the authors nevertheless performed a *post hoc* analysis and state that there were significantly different improvements for the groups. However, the authors do not correct their alpha level for this comparison. This approach, thus, leads to serious doubts about the validity of the values found. Furthermore, when the effect sizes of the physical performance measures for the control or IF instruction group are deduced from the values of the EF group, the resulting effect sizes are insignificant or small at best [35].

These observations are important because, empirical evidence is strong that the concealment of allocation sequence is associated with the effect size [23]. Inadequate reporting of allocation concealment in trial publications is common and has been associated with inflated effect size estimates [44-46], e.g., lack of blinding in RCTs has been shown to be associated with intervention effects that are exaggerated by 9% on average [47]. As can be derived from Figures 2 and 3, the observed ROB was especially problematic in this part of our analysis. With this in mind, the relationship between EF instructions and motor learning research and its effect in patient rehabilitation settings requires further exploration. Future adequately powered studies with low ROB and with rehabilitation populations that are followed over extended time periods should, therefore, be performed to substantiate or refute the assumption of the superiority of an EF in motor learning. An approach that strives for higher evidence standards, that uses large long-term trials and careful prospective meta-analyses of individual-level data may be better able to reach closer to the truth and clinically useful evidence [48,49].

On the basis of this systematic review, we cannot draw any conclusions for the most efficient way of motor learning for children, patients and the elderly, as data are scarce and raise doubts about the way they were collected. Based on the findings of this systematic review, the rules for the automaticity of motor skill learning in the healthy population cannot be transferred to populations in a rehabilitation setting, as currently, there are no data available that prove that this is correct. It can be speculated that the contribution of a conscious mode to motor skill learning is important for the early stages of learning a novel motor skill [7]. This conscious mode, which is connected to an IF of motor control, may be beneficial not only for the execution of skills with an esthetic aspect (like a gymnastic routine), but also for patients, the elderly and children. At least for the patients and children, this was corroborated by the findings of Cirstea and Emanuel [30,32].

It is generally appreciated that there are fewer demands on attention after practice [7]. When an actor (or mover) first performs a motor task, the unconscious mode cannot be used effectively; only in

a later phase, this transition will take place after hundreds of repetitions. These repetitions enable the actor to automate the sequencing, the perceptual-motor integration and the dynamic processes to be tuned. In the early phases of motor skill learning, conscious processes are therefore important [12]. This conscious mode only takes place at the beginning of the learning of the first few trials. In the phase of entering the development of automaticity in motor learning in healthy subjects, it is clear that when we then engage a conscious mode, the performance gets deteriorated. For automaticity, it is clear, that external cues are better in order to prevent a choking in motor performance [7,34]. This takes place when executing a task that can already be performed is brought back to consciousness. This is a phenomenon that we can easily observe in healthy adults who already can move: any more concentration on their own movements distracts from the aim of the movement and, therefore, deteriorates motor performance.

Linked to the time scale for the development of automaticity is the difficulty of the task [9]. A thumb finger opposition movement can be automated very quickly, whereas a perfect back-hand routine in tennis needs about one million repetitions before the task is automated [50]. For the motor learning of the latter, many different regions in the brain are involved, whereas for easy tasks, the primary motor cortex may be the main contributor [10,12]. Moreover, the central mechanisms of motor learning underlie different brain areas that control different aspects of motor learning [41]. For the awareness of a skilled action, a contribution of the prefrontal cortex and pre-supplementary motor area are necessary; for automated movements, timing errors are detected by the cerebellum and take place on an unconscious level. For the motor task to be learned, it is, therefore, clear that tasks that need a lot of involvement of the prefrontal cortex require different approaches in comparison to tasks that need little involvement of the prefrontal cortex and more involvement of the cerebellum [12].

## 9. Conclusion

In conclusion, we think that for the development of automaticity in goal-directed behavior in healthy adults, an EF of motor control might be the most profitable. For tuning into the environment, it is important to have the aim (or goal or target) integrated in the motor command, and therefore, the EF of motor control is more efficient for automating goal-directed behavior. However, only for the automaticity of goal-directed behavior, the “constrained action hypothesis” might be true. For exercises that do not need a target, like gymnastic routines, an EF of motor control is not advantageous, as, here, the movement execution itself is the aim of the movement. In summary, this means that, for trainers, occupational and physical therapists, it is very much dependent on the task and on the time-scale in which the motor learner is whether an IF or an EF is to be used for the learning of motor skills. The time-scale and motor learning capacity in patients may prevent them from entering in this phase of automaticity within hours and, in the case of patients, perhaps not even during the time of treatment (several months). The relationship between EF instructions and motor learning research and its effect in patient rehabilitation settings requires further exploration. Future adequately powered studies with low ROB and with rehabilitation populations that are followed over extended time periods should, therefore, be performed to substantiate or refute the assumption of the superiority of an EF in motor learning.

**Table 1.** Description of peer-reviewed articles on motor learning with internal or external focus of control, spec. design intervention group, participants, internal focus of control and external focus of control.

<b>Authors</b>	<b>Design intervention group (IGs)</b>	<b>Participants</b>	<b>Internal focus of motor control (IF)</b>	<b>External focus of motor control (EF)</b>
Cirstea (2007) [30]	2 IGs learn pointing movements with the impaired arm	stroke patients: 14 IF/14 EF	knowledge of performance (KP) about arm joint movements	knowledge of results (KR) about movement precision
de Bruin (2009) [29]	2 IGs train dynamic balance	elderly: 26 (>70)	on a moving point on a screen, which represents their point of gravity	on a moving point on a screen, which represents an air bubble in level
Emanuel (2008) [32]	2 IGs learn to throw darts	children: 34 adults: 30	on the movements of the shoulder, arm and fingers	on the target, the dart and dart's course
Freedman (2007) [33]	2 IGs learn hand and tongue impulse force control	students: 46	on the pressure they exerted with their hand/tongue	on the pressure on a bulb
Jackson (2011) [40]	4 IGs learn to balance with 2 foci of attention and 2 task objectives	adults: 36	on feet and are told that either feet position or board position is measured	on balancing board and are told that either feet position or board position is measured
Koedijker (2007) [34]	4 IGs learn implicitly, explicitly, environmental or movement oriented table tennis playing	students: 33	movement oriented focusses on movement components of wrist, elbow and shoulder	environmentally oriented focusses on movement of the ball
Lawrence (2011) [31]	3 IGs and 1 control learn new gymnastic routine	gymnasts: 40	on feeling of pressure under feet or on feeling in the face	on the exertion of pressure under the feet
Laufer (2007) [26] Rotem-Lehrer (2007) [25]	2 IGs receive balance training after ankle sprain	patients after ankle sprains: 40	on balance by stabilizing the body	on balance by stabilizing the platform
Makaruk (2012) [35]	2 IGs and 1 control have 9 weeks plyometric training	students: 36	on the extension of the lower limbs	on the force on the ground
Poolton (2006) [27] first exp.	2 IGs learn a golf putting task	adults: 30	on the swing of the hand	on the swing of the putter head
Poolton (2006) [27] second exp.	2 IGs learn golf putting task under increasing number of IF/EF rules	adults: 39	on the mechanical processes with more and more IF rules	on the effect of the movement with more and more EF rules
Porter (2010) [36]	2 IGs learn a standing long jump	young adults: 120	on the quickest extension of the knee	as far past the line as possible
Radlo (2002) [37]	2 IGs learn to throw darts	male students: 20	on the hand and elbow	on center of the board
Shea & Wulf (1999) [19]	2 IGs learn balance on stabilometer	students : 16	try to keep the feet on the same height	try to keep the markers at the same height
Wulf (1998) [28] first exp.	2 IGs and 1 control on ski-simulator	adults: 33	on the exertion of force on outer foot	on the exertion of force on outer wheels
Wulf (1998) [28] second exp.	2 IGs learn balance on stabilometer	students: 16	try to keep the feet on the same height	try to keep the markers at the same height
Wulf (1999) [39]	2 IGs hitting golf balls in a circle	students: 22	on body movements	on club movement
Wulf (2002) [38] second exp.	4 IGs learn to shoot lofted passes with a soccer ball with 33% or 100% feedback frequency	students familiar with soccer: 52	on their own movements	on the movement effect

**Table 2.** Description of peer-reviewed articles on motor learning with internal or external focus of control, spec. outcome variables, results and significance, training duration and retention.

Authors	Outcome variable	Results and significance	Training duration/Retention
Cirstea (2007) [30]	angular motion; inter-joint coordination trunk recruitment	with KP increase in joint range ( $p < 0.02$ ); better inter-joint coordination ( $p < 0.05$ ), but no trunk compensation; retention: KP better than KR ( $p < 0.05$ ); no 95% CI reported	10 1 h sessions for 2 weeks; 4 weeks later
de Bruin (2009) [29]	weight shifting score; dynamic balance parameters; falls efficacy; Extended Timed-Get-Up-and-Go test; 5 chair rises	all subjects improved, but no significant difference between IF and EF: no 95% confidence interval (CI) reported	2 weekly sessions for 5 weeks no retention test
Emanuel (2008) [32]	accuracy and variability of throws	acquisition: adults improved more on EF than on IF ( $p < 0.05$ ); children no difference; retention: no effect for age and focus of attention; transfer: EF better than IF for adults; IF better than EF for children; no 95% CI reported	50 throws on day 1 retention: 20 throws on day 2 transfer: 20 throws on day 2
Freedman (2007) [33]	absolute and variable error of the pressure bursts' peaks of hand and tongue	EF smaller absolute error ( $p = 0.05$ ) for the hand and tongue; EF smaller variable error for hand and tongue ( $p < 0.05$ ); no 95% CI reported	40 contractions for hand and tongue on day 1; no retention
Jackson (2011) [40]	root mean square error of platform angle	acquisition: EF and external aim were most efficient ( $p = 0.015$ ); retention: no interaction between focus of attention and task objective; no 95% CI reported	6 trials on each day (1, 2) 3 trials on day 3
Koedijker (2007) [34]	ball precision; stress level of subject; number of rules acquired and direction	acquisition: no difference pre- and post-learning for the 4 conditions; number of rules more important than direction of attention; no 95% CI reported	every condition 50 trials all on day 1; no retention test
Lawrence (2011) [31]	accurate movement form/ technique	acquisition: no significant differences between groups after two days; retention: no significant differences between groups after one week (or transfer); no 95% CI reported	40 trials in 2 days training retention: 5 trials 1 week later
Laufer (2007) [26] Rotem-Lehrer (2007) [25]	variance in overall stability of platform displacement and anteroposterior and mediolateral displacement	acquisition: no group effect for any of the three stability parameters; retention: no difference between EF and IF; EF improved significantly over time; no 95% CI reported	20 trials on 3 days (1,2,3); retention: 48 hours after day 3
Makaruk (2012) [35]	standing long jump (SLJ); countermovement jump (CMJ); drop jump (DJ)	SLJ: EF better than IF and C ( $p < 0.000$ ); CMJ: EF better than IF and C ( $p < 0.007$ ); DJ: C better than IF ( $p < 0.05$ ); no differences between EF and IF; no 95% CI reported	first 1-7 weeks 3 × 50 minutes/ week; weeks 8-9: 2 sessions

Table 2. cont.

1. Poolton (2006) [27]	number of successful puts	acquisition: no difference between EF and IF; retention: no difference between EF and IF; transfer (=distraction): EF better than IF ( $p < 0.05$ ); no 95% CI reported	300 trials on one day another 2 × 30 for retention
2. Poolton (2006) [27]	number of successful puts	acquisition: no difference between EF and IF; retention: no difference between EF and IF; transfer (=distraction): EF and IF deteriorate ( $p < 0.01$ ); no 95% CI reported	300 trials on one day another 2 × 30 for retention
Porter (2010) [36]	distance jumped	EF jumped further as IF ( $p < 0.003$ ); 95% CI: 3.32 - 16.74	5 trials on one day; no follow-up
Radlo (2002) [37]	magnitude of EEG alpha power; heart rate; correctness of throws	EF produced less alpha power ( $p < 0.0003$ ), lower heart rate ( $p < 0.0001$ ), less absolute error ( $p < 0.05$ ); no 95% CI reported	40 trials on one day no follow-up
Shea & Wulf (1999) [19]	RMSE of balance on stabilometer	first 7 trials: IF better than EF; second 7 trials: no difference between IF and EF; retention: EF better than IF ( $p < 0.05$ ); no 95% CI reported	7 trials on 2 following days day 3: 7 trials
1. Wulf (1998) [28]	movement amplitude and frequency	movement amplitude: EF better than IF and control ( $p < 0.05$ ); movement frequency: no difference ( $p > 0.05$ ); retention: movement amplitude: EF better than IF and control ( $p < 0.05$ ); movement frequency: no group differences;	8 trials on each day (1,2) 6 trials on day 3
2. Wulf (1998) [28]	RMSE of balance on stabilometer	acquisition: no difference between IF and EF; retention: EF better than IF ( $p < 0.01$ ); no 95% CI reported	7 trials on 2 following days day 3: 7 trials
Wulf (1999) [39]	measure of success on five point scale	acquisition: EF better than IF ( $p < 0.001$ ); retention: EF better than IF ( $p < 0.018$ ); no 95% CI reported	80 trials on day 1 30 trials on day 2
2. Wulf (2002) [38]	movement accuracy on 4-point scale	acquisition: EF better than IF ( $p < 0.05$ ); no main effect for frequency of feedback; retention: EF better IF ( $p < 0.01$ ); no main effect for frequency of feedback; no 95% CI reported	30 trials on day 1 10 trials one week later
Wulf (2001) [15]	RSME in degrees of balance; RSME with <i>versus</i> without RT; mean power frequency (MPF); probe RT	RMSE: no difference between EF and IF ( $p > 0.05$ ); RMSE with vs. without RT: no effect of task type; Probe RT: no effect of attention focus ( $p > 0.05$ ); retention: RMSE: IF > EF ( $p < 0.01$ ); RMSE with versus without RT: no difference; MPF: EF > IF ( $p < 0.01$ ); Probe RT: EF < IF ( $p < 0.01$ ); no 95% CI reported	7 trials on each day (1,2) 7 trials on day 3

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