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# How to interpret cognitive training studies: A reply to Lindskog & Winman

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ABSTRACT

In our previous studies, we demonstrated that repeated training on an approximate arithmetic task selectively improves symbolic arithmetic performance (Park & Brannon, 2013, 2014). We proposed that mental manipulation of quantity is the common cognitive component between approximate arithmetic and symbolic arithmetic, driving the causal relationship between the two. In a commentary to our work, Lindskog and Winman argue that there is no evidence of performance improvement during approximate arithmetic training and that this challenges the proposed causal relationship between approximate arithmetic and symbolic arithmetic. Here, we argue that causality in cognitive training experiments is interpreted from the selectivity of transfer effects and does not hinge upon improved performance in the training task. This is because changes in the unobservable cognitive elements underlying the transfer effect may not be observable from performance measures in the training task. We also question the validity of Lindskog and Winman's simulation approach for testing for a training effect, given that simulations require a valid and sufficient model of a decision process, which is often difficult to achieve. Finally we provide an empirical approach to testing the training effects in adaptive training. Our analysis reveals new evidence that approximate arithmetic performance improved over the course of training in Park and Brannon (2014). We maintain that our data supports the conclusion that approximate arithmetic training leads to improvement in symbolic arithmetic driven by the common cognitive component of mental quantity manipulation.



## 1. Introduction

Imagine yourself in a six-day weight-training program. On the first day, you start squatting 80 lb. Then, you increase the weight adaptively on a daily basis until the last day when you squat 150 lb. Prior to this weight-training program, you could lift up to 200 lb; therefore, technically your *weight-lifting* performance did not improve. Nevertheless, after the six days of squatting, you find that you are able to sprint faster than you previously could! Whether your squatting performance improved or not has little to do with demonstrating the causal relationship between squatting and sprinting and its translational significance (Chelly et al., 2009; McBride et al., 2009). The essence of that causal relationship is *not* between squatting and sprinting but between *strengthening leg muscles* and sprinting.

Lindskog and Winman's (2016) commentary on our previous paper (Park & Brannon, 2014) claim that there is no evidence of *performance improvement*[1] in our non-symbolic approximate

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[1] Note that Lindskog and Winman actually argue that there is "no evidence of *learning*." However, they conflate performance improvement in the observable measures with possible changes in unobserved cognitive elements due to training (see Section 2). We suggest to reserve the term learning for the latter, and that it is more accurate to use the term *performance improvement* in this case.

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arithmetic condition and suggest that this undermines the conclusion that there is a causal relationship between approximate arithmetic training and symbolic arithmetic. Here we argue that regardless of whether there is evidence of improvement in a training task, evidence of selective transfer implicates a causal relationship between the training and transfer task. Furthermore we present new empirical evidence for improved performance in the approximate arithmetic training task. We maintain that our data supports the conclusion that approximate arithmetic training and symbolic arithmetic share a common cognitive element that is not shared by a host of other training tasks that we used as control conditions. We hypothesize that the cognitive element is the shared mental manipulation required by both approximate arithmetic and symbolic arithmetic.

## 2. Interpreting the effect of cognitive training does not require an improvement in the training task

L&W argue that there is no evidence that participants trained on solving approximate arithmetic in Park and Brannon (2013, 2014) learned to solve the task better over the course of training, and therefore that the proposed causal nature between approximate arithmetic and symbolic arithmetic should be questioned. We argue that (1) they conflate performance improvement in the observable measures with possible changes in an unobserved cognitive element that may actually explain transfer effects and (2) that transfer effects in cognitive training studies do not hinge upon evidence of improved performance in the training task.

A typical cognitive training study involves multiple sessions of a demanding *training* task, with a *target* task administered once prior to this training (pretest) and once after this training (posttest). The logic behind this paradigm is that if the cognitive elements of the training task are causally related to the cognitive elements of the target task, then repeated performance of the training task will improve the performance of the target task. Importantly, carefully designed control training task(s) and control target task(s) are critical in claiming the specificity of the causal relationship between the training and the target task. For instance, if a given training task not only improves performance in a hypothesized target task but also improves performance in other target tasks, then the causal relationship may be of less theoretical importance (albeit it may still be practically or educationally useful). Similarly, if performance in the hypothesized target task is improved not only by the hypothesized training task but also by other training tasks, then improved target task performance may be due to a test–retest effect.

One important aspect of this logic, for the purpose of present discussion, is that the interpretation of causality is between the *unobserved* cognitive elements of the training and the target tasks. As in our weight-training example above, if repeated squatting (training task) strengthens leg muscles (underlying element of the training task), then strengthened leg muscles (underlying element of the target task) could improve sprinting (target task). Thus, whether observable performance in the training task improves or not is not relevant for interpreting the cognitive training effect (i.e., improvement in the target task). Rather, it is the improvement, facilitation, strengthening, or growth of the unobservable cognitive elements that is important in the interpretation of cognitive training.[2] Nevertheless, L&W conflate observable performance improvement in training tasks with possible changes in such an unobserved cognitive element. There may be many reasons why changes in the unobservable cognitive elements *do not* yield a change in the observable behavioral measure. As in the weight-training example, one scenario is that the adaptive progression of the training task does not push beyond individual capacity (i.e., over six days of weight training, you were only asked to lift up to 150 lb while your maximum capacity is in fact 200 lb). Another scenario may be that the changes in the unobservable cognitive elements do not directly enhance skills and strategies to perform the training task in short term.

Collectively in two papers we showed with three independent samples of participants that training approximate arithmetic improved symbolic math and did not improve a host of other target tasks (vocabulary, numerical-order judgment, approximate number comparison, and spatial 2-back; Park & Brannon, 2013, 2014). These three different samples were contrasted with a no-contact control condition, a condition for which participants were trained in answering multiple choice trivia questions, a spatial working memory condition, a numeral ordering condition, an approximate numerosity comparison condition, or an approximate numerosity matching condition. We found that approximate arithmetic training improved symbolic arithmetic performance in contrast to all of the other training conditions. We interpret these results to indicate that the unobservable cognitive element causally linking approximate arithmetic and symbolic arithmetic is something that is present in the approximate arithmetic task but not in the other control training tasks. Moreover, the fact that approximate arithmetic training improved symbolic arithmetic but did not improve performance on a variety of other cognitive tasks, suggests that this unobservable cognitive element selectively influenced symbolic arithmetic. We argued that these findings provide evidence for a causal link between approximate arithmetic and symbolic arithmetic driven by the facilitation in the manipulation of nonverbal numerical quantity.

Thus our first objection to the L&W commentary is that we disagree with their primary argument that no evidence of performance improvement over training nullifies the selective improvement we found in a cognitive training design. Instead, we argue that observable performance increases are not necessary to conclude that a training task has a selective benefit on a transfer task.

## 3. L&W's alternative explanations are ad hoc

Our hypothesis that improvements in symbolic arithmetic are driven by the facilitation of nonverbal quantity manipulation is falsifiable and could indeed be incorrect. There may be other unobservable cognitive elements (that we are unaware of at this point) distinctively present in the approximate arithmetic but not in all other control training tasks, which may have led to improvements in symbolic arithmetic. However, L&W have not offered a hypothetical compelling alternative, and more importantly they have not offered any data in support of the ad hoc alternatives they propose.

### *3.1. The priming hypothesis*

L&W argue that "priming" of the "approximate numeric processes [may have been] ... transferred to the symbolic arithmetic test." First, L&W's use of the word priming is unclear. They raise an example from a *perceptual priming* study (e.g., when given a word-fragment completion task, it is faster and easier to complete [aa_d_a_k] after seeing the word aardvark) demonstrating that priming effects can last up to 17 years (Mitchell, 2006). However,

[2] In the case of working memory training, one study found that improvement in the target task was only observed in participants who showed an improvement in the training task (Jaeggi, Buschkuehl, Jonides, & Shah, 2011). Such a finding, however, does not argue against the idea that observable measures may not be directly driven by changes in an unobserved cognitive element.