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Self-regulated learning as a mediator of the relation between executive functions and preschool academic competence

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ABSTRACT

Executive functions (EF) and self-regulated learning (SRL) are processes for the goal-directed control of cognition and (learning) behavior that positively affect academic outcomes. Based on the finding that EF form the developmental basis for SRL, this study tested a model that assumes SRL as a mediator of the relationship between preschool EF and academic competence. Previous studies that found evidence for this mediation considered as predictors cool EF, which are important in emotionally neutral situations. However, since (pre) school-based learning is also associated with motivational incentives (e.g., praise from teachers and educators), this study aimed to test the validity of the above-mentioned mediation model using as predictors hot EF, which are important in emotional–motivational contexts. To this end, the constructs included in the model were cross-sectionally examined using performance measures and parent ratings in a sample of $n = 77$ German preschoolers ($M_{age} = 71.61$ months, $SD = 4.13$; 51.9 % girls). Results show that SRL mediates the relationship between hot EF and academic competence. Methodological limitations of the present study and implications for research and practice are discussed.

1. Introduction

When children enter elementary school, they must align their behavior closely with goals such as completing homework or studying for exams. In order to achieve these goals, it is important that they initiate higher-order cognitive processes for the goal-directed control of their thoughts and actions: these processes are grouped under the term *executive functions* (EF; Karbach & Unger, 2014). When the goals set relate to learning behavior, *self-regulated learning* (SRL) plays an important role along with EF. SRL describes the learner's active process of controlling their cognition, motivation, and behavior based on self-set learning goals (Pintrich, 2000). The similarity of the definitions already suggests that the two constructs are related. Since they originate from different research traditions (EF are usually studied in neurocognitive and developmental psychology, and SRL in educational psychology), their relationship and, in particular, the potential direction of this relationship have been little studied so far (e.g., Davis et al., 2021; Rutherford et al., 2018). However, research on the relevance of both constructs in the academic context has a long tradition, to the extent that the predictability of academic competence by both EF and SRL has already been meta-analytically validated (Cortés Pascual et al., 2019; Dent & Koenka, 2016). Even for children of preschool age, an early developmental phase for EF and SRL, cross-sectional and longitudinal studies have found evidence for the predictability of academic competence by EF and SRL (Bryce et al., 2015; Duncan et al., 2017; Howard et al., 2022; Howse et al., 2003). Furthermore, previous research has shown that both preschool EF and SRL skills can be increased through training in the respective skills (e.g., Perels et al., 2009; Thorell et al., 2009).

The aim of the present study is to connect the two research traditions on EF and SRL and examine how the two constructs interact in predicting academic competence in preschoolers. The results of the study will facilitate the development of questions for future intervention studies on EF and SRL regarding the possible transfer effects of the constructs on each other as well as on academic competence and thus contribute to ensuring a successful entry to school for preschoolers. To this end, the theoretical framework of EF and then SRL are first presented below. Subsequently, the development of the two constructs is considered together in order to derive statements as to the direction of the relationship between them. Finally, a predictive model for academic competence is constructed based on the discussion.

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1.1. Theoretical modeling of EF

EF comprise a variety of cognitive processes, such as task instruction maintenance, attentional control, and error monitoring (e.g., Baggetta & Alexander, 2016; Doebel, 2020). Accordingly, researchers have sought to create models that summarize this multiplicity of functions in fewer higher-order dimensions (e.g., Baddeley & Hitch, 1974; Miyake et al., 2000). A frequently cited model of EF is that devised by Miyake et al. (2000). The authors had college students complete various tasks to measure EF and, using structural equation modeling, were able to identify three distinct EF factors: updating, inhibition, and shifting. These factors were interrelated, but they did not correlate highly enough to assume a general EF factor (Miyake et al., 2000). However, the three-factor structure of updating, inhibition, and shifting has not yet been observed in children of preschool age, when cognitive abilities are still poorly differentiated (Karr et al., 2018). For this reason, another EF model will be presented here, which makes certain assumptions about EF development and can accordingly be applied to children of preschool age.

In this model, Zelazo and Carlson (2012) postulate that EF processes differ depending on the emotional salience of situations: In situations with emotional–motivational features, so-called *hot EF* are relevant. This term refers to processes that enable behavioral control based on expected rewards or punishments (Zelazo et al., 2010). In affectively neutral situations, however, *cool EF* are significant. These enable complex task-goal-oriented behavior without linking goal achievement (or lack of it) to receipt of a reward (or punishment; e.g., Zelazo, 2006). Empirical evidence for the separation of the two EF subconstructs comes from studies that have identified hot and cool EF as distinct but correlated factors that are differentially related to other abilities, such as the ability to concentrate as well as reading and mathematical competence, even at kindergarten and preschool age (e.g., Brock et al., 2009; Willoughby et al., 2011).

To measure hot EF, tasks are used in which subjects can achieve rewards or punishments through their behavior. For adolescents and adults, gambling tasks are often used for this purpose, while for children, the tasks used tend to be those involving the delaying of gratification, such as the gift-wrapping task (Kochanska et al., 2000). Cool EF, on the other hand, are usually measured using abstract problem-solving tasks with no motivational incentive (other than verbal feedback), such as the Wisconsin Card Sorting Test (Grant & Berg, 1948).

In everyday life, however, hot and cool EF are difficult to separate since many problem situations with emotional–motivational features also require the more complex processes of cool EF. An example of this is schoolwork, which is emotionally connected with the hope of good grades and/or the fear of bad grades, but whose completion also requires abstract processes such as reflection. In this context, those goal achievement processes that have been described above as SRL are also relevant. How these processes can be structured will be described in the following section.

1.2. Theoretical modeling of SRL

Two types of SRL models can be distinguished: component and process models. Component models describe relatively stable competencies of individuals that enable SRL (e.g., Boekaerts, 1999); process models describe SRL as a sequence of phases (Wirth & Leutner, 2008). Process models do not focus on enduring characteristics and therefore provide a suitable basis for training. Since the present study is also intended to provide a basis for training (and transfer) design, process models are of particular interest. One frequently cited process model is Zimmerman (2000) social–cognitive model. This model assumes three successive, cyclical phases: a preactional forethought phase, an actional phase of performance and volitional control, and a postactional self-reflection phase (Zimmerman, 2000). During the forethought phase, learners plan their learning behavior and motivate themselves for the behavior. In the performance and volitional control phase, they employ learning strategies, monitor their learning behavior, adjust it if necessary, and employ volitional strategies to persevere in learning. In the self-reflection phase, learners check whether they have achieved their goals, make causal attributions for their success or failure in achieving their goals, and draw conclusions for future learning situations. The circle leading to the next forethought phase is closed by the plans that result from these conclusions for future learning (Zimmerman, 2000). This model illustrates that during the SRL process, cognitive, metacognitive, and emotional–motivational strategies are all important (see Boekaerts, 1999).

The assessment of these strategies is frequently conducted through self-report measures, such as learning diaries or questionnaires (e.g., Dörrenbächer & Perels, 2016; Schmitz & Wiese, 2006). However, these methods are difficult to implement for preschoolers because their brains are still maturing: preschoolers' (meta-)cognitive abilities are not yet sufficient to recall SRL strategies used in the past (Maylor & Logie, 2010), and their motivation is not yet sufficient for test compliance if the measurement tool is not enriched with playful elements (Stephenson & Hanley, 2010). Therefore, external ratings by caregivers are often used to assess observable preschool SRL skills (e.g., McDermott et al., 2002; Whitebread et al., 2009). Additionally, in recent years, researchers have developed scenario-based SRL tests in which the child is presented with problem situations that require the use of SRL strategies (e.g., Jacob et al., 2019; Maag Merki et al., 2013). The child's task is to evaluate different possible solutions to these situations. Test compliance can be increased by designing the test in a child-friendly way, for example, by embedding it in a picture story (Jacob et al., 2019).

The above-mentioned maturational processes in the child's brain also mean that SRL and EF competencies are not yet fully developed at preschool age (e.g., Best et al., 2009; Jeong & Frye, 2020). Therefore, the development of these skills, especially with regard to the direction of the relationship between them, will be described in the following section.

1.3. Development of EF and SRL and their interplay in predicting academic competence

With respect to EF, Zelazo and Carlson (2012) assume that the development of hot EF takes longer than that of cold EF. They refer to studies that found that performance gains in hot EF measures can be detected at an age when performance in cool EF measures is already stagnant (e.g.,Hooper et al., 2004 ; Prencipe et al., 2011). Since this study focuses on hot EF, its development will be presented in more detail.

According to Zelazo and Carlson (2012), the first developmental progress in hot EF is evident from the age of four. It is at this age or later that the majority of children succeed for the first time in pointing to the smaller of two rewards in order to receive the larger one (Carlson et al., 2005). The ability to delay gratification, however, develops in subsequent years and is not yet fully developed at preschool age (Mischel et al., 1989). Further developmental progress in hot EF is made through late adolescence and adulthood, as evidenced, for example, by performance gains in gambling tasks (Hooper et al., 2004; Prencipe et al., 2011). Thus, basal hot EF skills are already present at preschool age, but much of the development expected in this area is still pending at this point.

A similar developmental course can be seen for SRL competencies: Preschoolers use initial SRL strategies, such as goal setting in Zimmerman (2000) forethought phase (Bronson, 2000), monitoring in the performance and volitional control phase (Schneider, 2008), and outcome evaluation in the self-reflection phase (Bryce et al., 2015). With increasing age and the accompanying maturation of (meta-)cognitive and motivational processes, the SRL strategies used gain in complexity. For example, children start considering the difficulty of a learning task when planning their learning behavior while school-age (Wellman, 1978). Knowledge of learning strategies continues to increase into adulthood (Schneider, 2008).

Since both EF and SRL involve control processes for goal-directed behavioral adaptation, substantial relationships emerge between the two constructs (Effeney et al., 2013; Garner, 2009). Therefore, a significant question from a developmental psychology perspective is which of the two constructs influences the other. To date, there has been little research on this question, but an answer can be derived from a framework modeled by Bailey and Jones (2019). The authors assume that EF are domain-general core processes that form the foundation for the development of domain-specific regulatory components, namely cognitive, emotional, and social regulation. Because SRL encompasses (meta-)cognitive and emotional–motivational regulation strategies (Boekaerts, 1999), it is found in the first two domain-specific regulatory components. Accordingly, EF can be expected to influence SRL. Results from studies concerning samples of adolescents and young adults support this assumption by identifying EF as cross-sectional predictors of SRL (e.g., Effeney et al., 2013; Follmer & Sperling, 2016). The first empirical evidence for the assumption of EF as an SRL-influencing predictor using longitudinal data was found by Davis et al. (2021). They measured EF and SRL in preschoolers at two time points one year apart and compared prediction models representing different relationships between the constructs with regard to their predictive quality. EF proved to be significant predictors for SRL, but the reverse was not the case (Davis et al., 2021).

Based on these considerations, we can assume that EF form basic competencies that enable successful SRL. These competencies include, for example, planning and attentional control, which enable children to engage in purposeful learning activities and thus successfully acquire academic skills (Rutherford et al., 2018). Combining the assumptions and empirical results described above into a predictive model of academic competence, it can be further assumed that the relationship between EF and academic competence is mediated by SRL. Although numerous studies have identified one or other of the two constructs as a predictor of different facets of academic competence, for example, mathematical reasoning or reading competence (Cortés Pascual et al., 2019; Dent & Koenka, 2016), the authors of the present study are aware of only two studies that test such a mediation model: Rutherford et al. (2018) were able to find that the relationship between cool EF and academic competence (specifically mathematical achievement) was partially mediated by SRL in elementary school children. Similarly, a study by Neuenschwander et al. (2012) also identified SRL[1] as a partial mediator of the relationship between cool EF and academic competence (represented by school grades). However, (pre)school learning is not exclusively characterized by "cool," that is, abstract cognitive activities, but takes place in a "hot," that is, emotionally–motivationally enriched context: for example, learners hope for rewards such as good grades and positive feedback in the form of praise or smiley face drawings from teachers. Consequently, hot EF should also influence learning behavior and, ultimately, learning outcomes. Therefore, the aim of the present study was to test whether this mediation model was also valid with hot EF as predictors. Since even preschool EF and SRL are significant predictors of academic competence (e.g., Kim & Nor, 2019; Sasser et al., 2015; Verdine et al., 2014) a mediation model was tested on a sample of preschoolers so that the results might be used for preschool intervention studies aimed at helping children enter school. Based on the theory and empirical results described above, the following hypotheses were adopted:

H1. Preschoolers' hot EF are significant predictors of preschoolers' academic competence.

H2. Preschoolers' SRL is a significant predictor of preschoolers' academic competence.

H3. Preschoolers' hot EF are significant predictors of preschoolers' SRL.

H4. The relationship between preschoolers' hot EF and their academic competence is mediated (at least partially) by preschool SRL.

2. Methods

The ethical standards of the Ethics Committee of the Faculty for Empirical Human Sciences and Economical Sciences (Saarland University) were followed in the conduct of the study. The parents of the participating children gave their written consent after being informed in detail about the study content, and the children gave their verbal consent to participate in the study. The data were collected anonymously using codes in place of participant names. The children participated in the tests voluntarily and could interrupt them at any time. Such a decision did not cause them any disadvantages. The parents of the subjects also participated voluntarily in the parent survey and were able to refrain from answering individual questions in the parent questionnaire without any resulting disadvantage to them or their children. As a mark of thanks for their participation, children received a small gift.

2.1. Participants and procedure

Our calculation of the required sample size was based on the simulation study by Fritz and MacKinnon (2007). According to this study, 78 subjects are needed to achieve a power of $\beta = 0.80$ ($\alpha = 0.05$) if one uses bootstrapping to check for the existence of mediation effects and one assumes medium path sizes of $\beta = 0.39$ for the paths between predictor and mediator as well as between mediator and criterion (Fritz & MacKinnon, 2007). Because experience from past studies (e.g., Venitz & Perels, 2019) indicated that approximately one-third of parent questionnaires would not be returned, we recruited $N = 78 + 0.33 * 78 = 103$ German preschoolers[2] for the present study. We subsequently excluded $n = 20$ children for whom no data were available from the parent questionnaire. A further $n = 5$ children were excluded because they refused to participate in individual tests. In addition, $n = 1$ child who refused to complete more than 25 % of a test was excluded from the analysis. (If children or parents refused to answer less than 25 % of items, their scores for these items were estimated using the expectation maximization method.) Thus, the final sample consisted of $n = 77$ preschoolers ($M_{age} = 71.61$ months, $SD = 4.13$; 51.9 % female). Of these children, 85.7 % came from German-speaking homes, 9.1 % from bilingual homes with German and another native language, 2.6 % from English-speaking homes, and 1.3 % each from Arabic- and Russian-speaking homes. All children had normal or corrected-to-normal vision. Data collection used a cross-sectional design. To ensure adequate concentration capacity, testing was conducted individually. Testing sessions lasted approximately 30 min. We measured all constructs as part of individual testing using performance measures. Children's SRL and academic competence were additionally assessed using parent ratings. Testing was conducted by PhD students and students in the bachelor's and master's programs in psychology, who received extensive training in test administration and recording. The use of test manuals additionally ensured standardized and objective procedures.

[1] That study does not explicitly employ the term SRL; instead, the term "learning-related behavior" is used. However, this includes behaviors that are relevant to SRL, such as persistence and dealing with distraction.

[2] In the German education system, kindergarten is followed by school entry at around six to seven years of age. The last year of kindergarten, which is attended at around five to six years of age, is therefore referred to as preschool age in Germany.

2.2. Measures

2.2.1. Hot EF

We used the gift-wrapping task (Kochanska et al., 2000) to measure preschoolers' hot EF. In this task, the child was told that they would receive a small gift to thank them for their participation and that the experimenter still needed to wrap this gift. The child was instructed not to look at or turn toward the experimenter, who was located at a table next to the child, during the wrapping procedure, which took 60 s. The child was filmed for this period. After the test, two independent, trained raters used the video to assess latency to look (0 to a maximum of 60 s if no looking was done) and latency to turn (0 to a maximum of 60 s if no turning was done). Training of raters was conducted using example videos that were not from the study sample. The agreement of observer ratings in the study was in the excellent range with $ICC = 0.93$ for latency to look and $ICC = 0.91$ for latency to turn (Koo & Li, 2016). Therefore, we calculated the average rating of the two ratings for each measure. The measures latency to look and latency to turn correlated significantly with each other ($r = 0.85$, $p < .001$).

2.2.2. SRL

Preschoolers' SRL was assessed using a performance-based and a parent rating–based measure. The performance-based measurement method used was a revised version of the scenario-based SRL knowledge test devised by Jacob et al. (2019). This test took the form of a picture story that was read to the child. Within this story, the protagonist encounters various situations that require the use of SRL strategies (e.g., comparing a self-made craft to a template in a craft book used as goal representation). For each situation, two ideas for possible actions (items) are given, one of which is an SRL strategy (target) and one of which is a behavior that does not serve the protagonist's goal (distractor). The child's task was to judge the usefulness of each idea on a four-point answer scale visualized with colored circles (green to red). The scale ranged from a bright red circle meaning *not so great idea* through a pale red circle and a pale green circle to a bright green circle meaning *really great idea*. An example scenario with corresponding target and distractor items is given in Appendix A. The child's performance was determined by pair comparisons. If, within one scenario, the target item was rated as better than the distractor item, the child received one point. No point was given if the target item was rated as being as good as or worse than the distractor item. With a total number of 14 scenarios, a total of 0 to 14 points was possible. The test showed satisfactory reliability in the present sample (Cronbach's $\alpha = 0.72$). As an initial measure of the validity of this new scenario-based SRL knowledge test, we used the COMPSCALE (Lange et al., 1989), which served in the present study as an instrument for parental rating of children's SRL competencies (see below). We found a significant correlation between the two measures ($r = 0.27$, $p = .009$).

We used a German translation of the COMPSCALE (Instrumental Competence Scale for Young Children; Lange et al., 1989) as the measure for parental ratings of SRL. This rating scale consists of 27 items describing child SRL behaviors (e.g., "Plans and carries out multistep activities"). For each behavior, the parent indicated the extent to which the child showed it. The answer was given on a seven-point Likert Scale ranging from 1 = *strongly disagree* to 7 = *strongly agree*. A total of up to 189 points was therefore possible. The COMPSCALE showed satisfactory reliability in the present sample (Cronbach's $\alpha = 0.77$).

2.2.3. Academic competence

We also assessed preschoolers' academic competence using a performance-based and a parent rating–based measure. As a performance-based measure, we used an adapted version of the Logical–Mathematical Reasoning test (in German "Test Logisch–Mathematisches Denken") from the German version of the IDS-2 (Intelligence and Development Scales – 2; Grob & Hagmann-von Arx, 2018). The test adapted for the present study consisted of seven subtests, each with one to four items. Each subtest relates to a basic mathematical skill: the first measures counting skills; the second, understanding of ordinal numbers; the third, understanding of quantities; the fourth, assigning digits to quantities; the fifth, recognizing invariance; the sixth, mental addition skills; and the seventh, solving simple equations. The tasks are designed to be child-friendly; for example, the understanding of ordinal numbers is assessed by placing six colored glass stones in front of the child and asking the child to point to the third (and in the next item to the fifth) glass stone without counting beforehand. In total, the adapted version of the test consists of 18 items, with one point for each correct solution. The child could therefore score a maximum of 18 points. The test showed an acceptable level of reliability in the present sample (Cronbach's $\alpha = 0.85$).

As a parental rating of academic competence, we used a self-constructed short scale representing expected school success. The scale consists of four items that include statements about future school success or failure. Two of the items were polarized with their reverse. (Example of normal-poled item: "The child will be able to achieve good grades at school." Example of reverse-poled item: "The child will be over-challenged by the demands of school.") Parents answered each item on a four-point Likert scale ranging from 1 = *strongly disagree* to 4 = *strongly agree*. A total of up to 16 points was therefore possible. The short scale showed a satisfactory level of reliability (Cronbach's $\alpha = 0.76$). It correlated significantly ($r = 0.28$, $p = .008$) with the adapted version of the Logical–Mathematical Reasoning test (Grob & Hagmann-von Arx, 2018), which can be taken as a first indication of the validity of the short scale.

2.3. Data analysis

Data were analyzed using the statistical program IBM SPSS, version 27. Due to the multi-method approach, we z-standardized the two scores per construct and then calculated the mean of the two z-values, resulting in one value (construct index) per construct. As the first step of data analysis, we calculated Pearson correlations between the construct indices. The next step was hypothesis testing. To statistically test Hypotheses 1 to 3, we calculated linear regressions. For the analysis concerning the fourth hypothesis, we used the PROCESS macro for SPSS (Hayes, 2017).

3. Results

3.1. Preliminary analyses

Descriptive statistics (means and standard deviations) of the measures collected for the mediation analyses are provided in Table 1. As the means of the hot EF measures as well as the parent rating of academic competence are relatively close to the possible maximum scores, we checked for ceiling effects. Ceiling effects are assumed to be present, if a

Table 1
Descriptive statistics of the measures for the assumed predictor, mediator, and criterion variables.

Variable	Range of possible scores	*M*	*SD*
Hot EF – latency to look	0–60	52.09	16.43
Hot EF – latency to turn	0–60	54.92	13.78
SRL – test	0–14	7.99	3.15
SRL – parent rating	27–189	148.15	17.24
Academic competence – test	0–18	11.66	3.68
Academic competence – parent rating	4–16	13.35	1.94

Note. EF = executive functions; SRL = self-regulated learning. Because the construct indices for hot EF, SRL, and academic competence are means of z-standardized values, they all have a mean of 0 and a standard deviation of 1. Therefore, they are not shown in this table.

proportion of at least 15 % of subjects achieves the possible maximum score (Terwee et al., 2007). We found ceiling effects for the latency to look measure (74 % reached the maximum score), for the latency to turn measure (82 % reached the maximum score), and for the parental rating of academic competence (21 % reached the maximum score). For the remaining measures, no ceiling effects were found, as only 1 % to 4 % reached the maximum scores in these measures.

For an initial overview of the relationships between the constructs, Table 2 shows the Pearson correlations between the different construct indices. While SRL is significantly correlated with the other two constructs, no significant correlation is seen between hot EF and academic competence.

3.2. Hypothesis testing

To test Hypotheses 1 to 3, we calculated linear regressions on the construct indices. The results of the regressions are shown in Table 3. Contrary to Hypothesis 1, hot EF did not turn out to be significant predictors of academic competence. However, consistent with Hypothesis 2, SRL was found to significantly predict academic competence. Furthermore, consistent with Hypothesis 3, we found that hot EF significantly predicted SRL.

Because the presence of a direct effect between predictor and criterion is not a necessary condition for mediation (Rucker et al., 2011; Zhao et al., 2010), we tested Hypothesis 4 despite the lack of significant prediction of academic competence by hot EF by testing the indirect path from hot EF via SRL to academic competence. For this, we considered the 95 % confidence interval (95 % CI) on the indirect effect[3] and checked whether it contained 0. A significant indirect effect exists if 0 is not included. In accordance with Hypothesis 4, we found a significant indirect effect, $\beta = 0.13$, 95 % CI [0.0027, 0.2545]. Since this is indirect-only mediation (presence of an indirect effect in the absence of a direct effect; Zhao et al., 2010), it can be assumed that full mediation is present. The mediation model resulting from this indirect effect is shown in Fig. 1.

4. Discussion

Based on the importance of EF and SRL for academic outcomes and the prior finding that the relationship between cool EF and academic competence is mediated by SRL, the present study aimed to examine whether such mediation was also present for hot EF as predictors. We measured preschool hot EF, SRL, and academic competence using multiple methods and examined whether hot EF and SRL predicted academic competence, whether hot EF predicted SRL, and whether hot EF exerted an indirect effect on academic competence via SRL as a mediator.

The results were only partially consistent with our hypotheses: in our study, hot EF failed to predict academic competence. However, in line with the hypotheses, we found that SRL predicted academic competence and hot EF predicted SRL. Likewise, we found evidence that hot EF exerted an indirect effect on academic competence mediated by SRL, with full mediation apparent.

Table 2
Correlations between the construct indices of the assumed predictor, mediator, and criterion variables.

Variable	(1) Hot EF	(2) SRL	(3) Academic competence
(1)	1.00		
(2)	0.32**	1.00	
(3)	0.03	0.37***	1.00

Note. EF = executive functions; SRL = self-regulated learning.
** $p < .01$.
*** $p < .001$.

Table 3
Statistical Parameters of the Regression Analyses for Hypotheses 1 to 3.

Hypothesis	Predictor variable	Criterion variable	Statistical parameters
H1	Hot EF	Academic competence	$\beta = 0.03$, $t(75) = 0.30$, $p = .384$
H2	SRL	Academic competence	$\beta = 0.37$, $t(75) = 3.43$, $p < .001$
H3	Hot EF	SRL	$\beta = 0.32$, $t(75) = 2.89$, $p = .005$

Note. EF = executive functions; SRL = self-regulated learning.

4.1. Discussion of results

The reported results are only partially in agreement with Neuenschwander et al. (2012) and Rutherford et al. (2018) findings regarding elementary school children. Consistent with these studies, we found evidence for an indirect effect of EF on academic competence through SRL, but in contrast to the previous studies, EF did not turn out to be significant predictors of academic competence. However, this difference in the results found should not be used to conclude that hot EF, unlike cool EF, do not predict academic competence: instead, alternative explanations for the results of the current study should be considered. The fact that an indirect effect of hot EF on academic competence could be found via SRL suggests that there is a relationship between hot EF and academic competence, but it was underpowered when tested. According to Rucker et al. (2011), such an underpowered direct effect may be present, for example, if the linkage of the predictor with the criterion is weak compared to the linkages of the mediator with the predictor and the criterion. The authors argue that this may be due to limitations in measurement accuracy for the predictor and the criterion. This may also have been the case in the present study: The fact that ceiling effects were evident for the hot EF variables as well as for the parental rating of academic competence, indicates that variance is limited in these measures. This may have made it difficult to find a significant relationship. For the performance-based measure of academic competence, however, no similar restriction was seen, since here only 4 % of the subjects reached the possible maximum score. Thus, an alternative explanation must be used for the missing relationship between hot EF and the Logical–Mathematical Reasoning test as the second measure of academic competence.

Such an alternative explanation could be given by considering differences in the sample from previous studies (Neuenschwander et al., 2012; Rutherford et al., 2018). The present study tested preschoolers, whereas the previous studies examined elementary school students. In Germany, where the present study was conducted, mathematical skills are not taught prior to elementary school, unlike in several other countries (e.g., the United States). Accordingly, mathematical skills at this age are still unaffected by formal instruction. Consequently, children in this age group have few opportunities to incorporate goal-directed (learning) behaviors as manifestations of (hot) EF and SRL into their mathematical abilities, so the relation of (hot) EF and SRL to logical–mathematical reasoning is still relatively low in this age group. Due to the low variance of the hot EF measurement, the relationship between hot EF and logical–mathematical reasoning in our sample might not yet have been detectable. Similarly, Neuenschwander et al. (2012), who found evidence for mediation of the relationship between cool EF and academic competence by SRL when using school grades but not when using standardized tests as a criterion, argue that school grades are based on performance assessments concerning the learning content actually taught, whereas standardized tests also ask about other content that is not part of that instruction and accordingly not directly

[3] The 95 % CI was calculated by bootstrapping with 5000 samples.

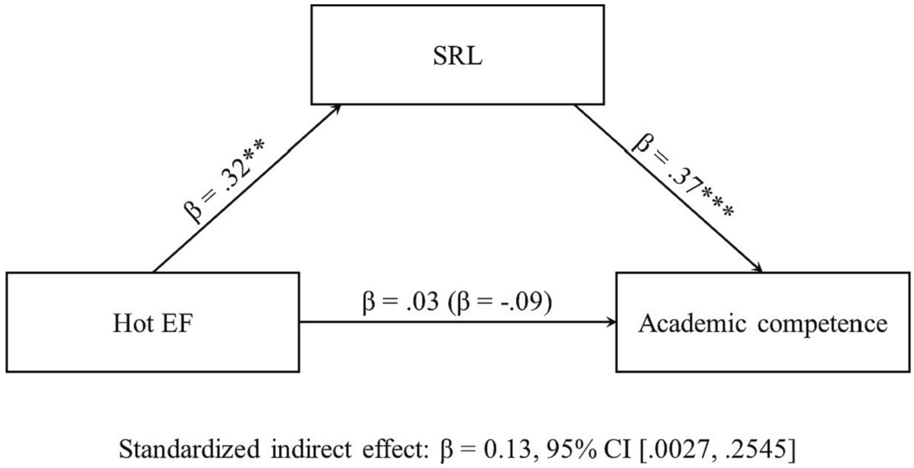

Fig. 1. Mediation Model with Regression Coefficients for the Included Paths
Note. EF = executive functions; SRL = self-regulated learning. The β in parentheses represents the weight of the regression coefficient when the mediator is used as a second predictor in the regression analysis.
* $p < .05$; ** $p < .01$; *** $p < .001$.

influenced by school learning. To test whether preschool hot EF can predict mathematical competence at the point when this has been influenced by school learning, a longitudinal study would be needed in which mathematical competence was measured (optimally using grades) following school entry, when children had experienced more opportunities for mathematical learning.

4.2. Limitations

As mentioned above, there are methodological limitations associated with the present study. First, the ceiling effects found for both the gift-wrapping task and the parental rating on expected school success indicate limited variance that may have impeded the detection of associations between the constructs. The finding of relationships between hot EF and academic competence was also hampered by the use of a performance-based academic competence measure that captures skills in an area of learning that is not taught until a later stage of education.

These limitations associated with measuring predictor and criterion may also explain why the paths between predictor and mediator as well as between mediator and criterion are of smaller sizes than we assumed for our calculation of required sample size (see Fig. 1 and Section 2.1). Accordingly, there were losses in power when testing the indirect effect. The fact that we still found a significant indirect effect from hot EF on academic competence via SRL, argues for the strength and stability of the indirect effect.

In addition, it should be noted as critique that a cross-sectional design was used to investigate the research questions. Thus, causal relationships between the variables can only be concluded on the basis of theoretical (Bailey & Jones, 2019) and empirical (Neuenschwander et al., 2012; Rutherford et al., 2018) preliminary work.

Furthermore, based on the available data, no conclusion can be drawn about the relative importance of hot EF versus cool EF in predicting SRL and, subsequently, academic competence, because only hot EF were measured. Since the two EF subconstructs are closely related (e.g., Brock et al., 2009; Willoughby et al., 2011), it cannot be ruled out that the effects found are exclusively due to shared variance of hot EF with cool EF.

4.3. Implications for practice and future research

The results of the present study again highlight the importance of goal-directed (learning) behavioral abilities for academic outcomes. They can be interpreted as an initial indication that preschoolers' hot EF, which play a role in motivational contexts, indirectly influence their academic competence by affecting their SRL. This finding points to a scissor effect (e.g., Traini et al., 2021): those children who are good at adapting their behavior to achieve goals in situations with emotional–motivational content at preschool age are also better able to regulate their learning process and will consequently achieve better academic outcomes. In contrast, children with lower levels of hot EF find it more difficult to structure their learning process autonomously, making them more likely to face failure in school. Considering the importance of school-based experiences of success for future learning motivation as well as healthy mental development (e.g., Çamdeviren et al., 2005; Deci & Ryan, 2008), the study results highlight the importance of identifying children with deficits in hot EF and SRL early. By training them in these competencies during preschool, educators may enable them to enter school with a sense of achievement that motivates them to continue learning. This paves the way for healthy mental development.

Initial implications for future research already emerge from the limitations mentioned above. For example, it would be desirable to test the assumed mediation model with an optimized methodological approach. The assessment of hot EF and academic competence would have to be adapted in order to generate greater variance. For this purpose, for example, the time taken for wrapping could be extended in the gift-wrapping task, or verbal comments could be made during wrapping to increase the temptation to seek a glimpse of the gift, such as, “That gift looks even more awesome than I remembered!” Alternatively, the task could be replaced, for example, with the gambling task, which is also used in older cohorts (e.g., Enke et al., 2022) and accordingly should not be overly easy for preschoolers.

In place of the parental rating, a teacher rating of expected school success could be used, since teachers should be better able than parents to assess the extent to which the behavior of a child being assessed is similar to that of the majority of children of the same age, given the large number of children with whom they interact on a daily basis (Lange et al., 1989). As a performance-based measure of academic competence, a test should be used that captures content that is already taught to children at preschool age. In countries such as the US, where basic mathematical competencies are already taught in preschool, the use of a test of mathematical abilities seems to make sense. In contrast, in countries without preschool mathematics instruction, such as Germany, an alternative measure would have to be found. In this context, for example, tests from the so-called school entry examination (in German “Schuleingangsuntersuchung”) would be appropriate, since these are used to check whether preschoolers have sufficiently developed all the competencies necessary for school entry. Ideally, the constructs would be assessed longitudinally. In addition to the opportunity this would provide to examine causal relationships, school grades could then also be used as a measure of academic competence to examine how subject-specific learning outcomes are influenced by EF and SRL.

Furthermore, in the context of future research into the relationships between the examined constructs, measurement methods for both hot and cool EF should be used as part of a holistic EF assessment in order to be able to generate statements about whether both components of EF contribute equally to the effective prediction of the constructs that follow in the course of development. For the criterion of academic competence, Brock et al. (2009) and Willoughby et al. (2011) found that hot EF could not explain variance in addition to cool EF, but as the results of the current study suggest, the findings may be different with respect to the indirect effect via SRL.

Alongside these changes, an additional measurement of child intelligence seems likely to be useful as intelligence is another significant factor influencing academic outcomes (e.g., Laidra et al., 2007; Soares et al., 2015). While the relationship between EF and intelligence has been well analyzed, showing significant associations (e.g., Duggan & Garcia-Barrera, 2015; Engelhardt et al., 2016), there is still relatively little research on a possible relationship between SRL and intelligence, which produced heterogeneous findings (Diseth, 2002; Zuffianò et al., 2013). Thus, a more detailed investigation of this relationship is likely to be useful, as well as research on the interplay between EF, SRL, and intelligence in predicting academic outcomes. In the study by Neuenschwander et al. (2012), intelligence was assessed in addition to EF and SRL, and the authors found that it did not explain variance in academic competence in addition to EF and SRL. However, it seems conceivable that the pattern of correlation could be different in preschool-age children due to the still early developmental stage of their goal-related and academic competencies. At this early stage of development, skills related to intelligence such as reasoning and problem-solving may facilitate the identification of strategies to achieve goals, thereby contributing to the stronger expression of EF, SRL, and consequently academic abilities. Consistent with this assumption, studies of knowledge acquisition (e.g., Schneider, 1996; Schneider et al., 1989) have also shown that as expertise increases, intelligence becomes less predictive of knowledge gain.

Finally, based on the relationships found between preschool EF, SRL, and academic competence, the question arises of whether preschool EF training leads to transfer effects in SRL and consequently academic competence. In addition to the fact that with the construct overlap of EF, SRL, and academic competence at preschool age, the basic prerequisite for a training transfer is given, Gunzenhauser and Nückles (2021) argue that the young target group of preschoolers in particular could benefit in its academic outcomes from EF training since instruction does not begin until children enter school and subject-specific prior knowledge at preschool age hardly plays a role in competence gains at that stage. EF could thus be a particularly strong factor influencing academic skill acquisition in this target group (similar to intelligence, as suggested above). Accordingly, EF training (mediated by transfer to SRL) could also lead to strengthening academic outcomes. This should be investigated in future research in order to enable children to start school with a sense of achievement.

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Declaration of competing interest

None.

Data availability

Data will be made available on request.

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Appendix A. Example scenario of the SRL strategy knowledge test with associated target and distractor item

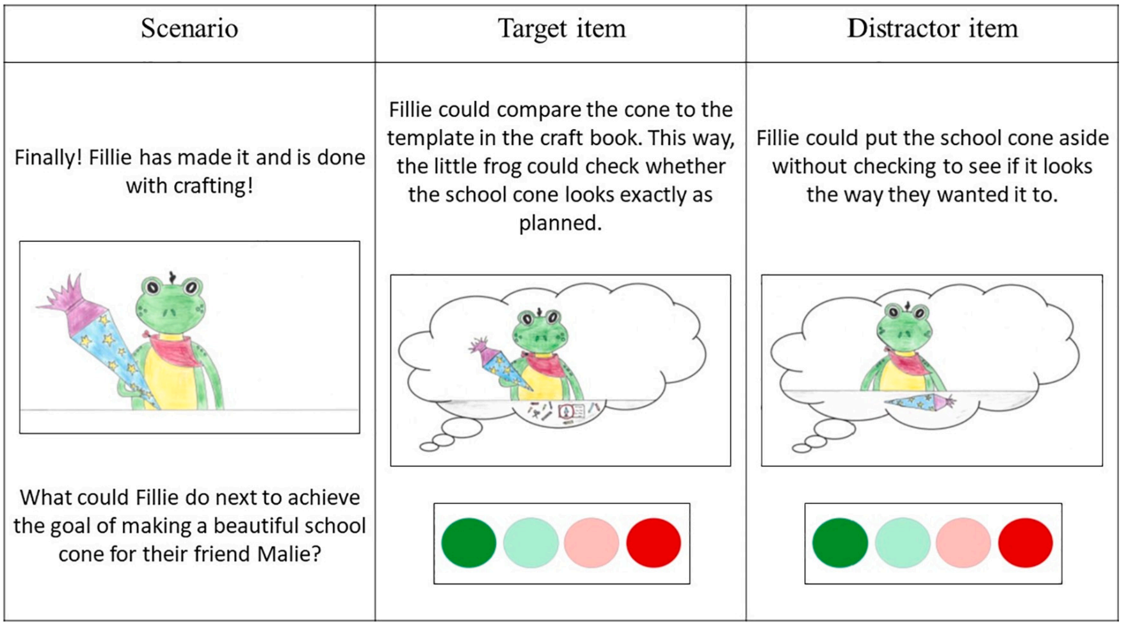

Fig. A1. Example Item of the SRL Strategy Knowledge Test for the Strategy Self-Evaluation in the Self-Reflection Phase.
Note. The test book is designed so that the child sees only one page (scenario, target, or distractor) at a time.
The order in which the items in a scenario (target and distractor) were presented was counterbalanced.

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