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Assessing Developmental Differences in Metacognitive Skills With Computer Logfiles: Gender by Age Interactions

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Abstract

Metacognitive skills regulate and control learning processes. A developmental study (Van der Stel & Veenman, 2014) revealed that metacognitive growth is interrupted at the age of 14-15 years, while metacognitive skills are generalized over tasks and domains at the same time. The present study seeks to confirm this pause or decline in metacognitive growth, however, with a gender-age interaction. Females are expected to run one year ahead of males in metacognitive development. Additionally, the usefulness of computer-logfile analysis as an unobtrusive method for assessing metacognitive development is investigated. A hundred and nineteen secondary-school students (66 male; 53 female) at the age of 13 to 16 years performed a computerized inductive-learning task. Traces of learner activities were stored in logfiles and automatically scored on metacognitive skills. Afterwards, participants completed a learning posttest. Results substantiate the expected gender-age interaction in the metacognition data. Females started low at 14 years, recovered at 15 years, and peaked at 16 years, whereas males started positive at 14 years, declined at 15 years, and recovered at 16 years. Posttest data show a significant effect of age with improved learning performance at 16 years. Implications for the study of metacognitive development are discussed.

Keywords: metacognitive skills, development, gender, logfile assessment

Introduction

Metacognition is a profound predictor of learning outcomes (Veenman, 2008; Wang, Haertel, & Walberg, 1990). Often knowledge of cognition is distinguished from regulation of cognition (Brown, 1987; Schraw & Dennison, 1994; Veenman,

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Van Hout-Wolters, & Afflerbach, 2006). Metacognitive knowledge is declarative knowledge about the interplay between person characteristics, task characteristics, and strategy characteristics (Flavell, 1979). Having declarative metacognitive knowledge at hand, however, does not guarantee that this knowledge is actually used for the regulation of learning behavior (Veenman et al., 2006; Winne, 1996). Metacognitive knowledge may be flawed or incomplete, the learner may fail to see the potential applicability of that knowledge in a particular situation, or the learner may lack the necessary skills for doing so. Metacognitive skills, on the other hand, refer to procedural knowledge for the actual regulation of, and control over one's learning behavior. Orientation, goal setting, planning, monitoring, evaluation, and recapitulation are manifestations of those skills (Veenman, 2011). Metacognitive skills directly shape learning behavior and, consequently, they affect learning outcomes. Veenman (2008) estimated that metacognitive skillfulness accounts for about 40% of variance in learning outcomes for a broad range of tasks.

Development of Metacognitive Skills

Although the development of metacognitive skills is assumed to commence at the age of 8 to 9 years (Veenman, 2011), children younger than 8 years are not entirely devoid of metacognitive skills if the task is tailored to their interest and level of understanding. Even 5-year-old children may demonstrate elementary forms of planning and self-correction in playful situations, such as distributing dolls over a limited number of chairs (Whitebread et al., 2009). Apparently, metacognitive skills start to develop at a basic level during early childhood years, but they become more sophisticated and academically oriented when formal education requires the utilization of a metacognitive repertoire (Veenman, 2011). From the age of 8 years on, children show a steep increase in frequency and quality of metacognitive skills (Alexander, Carr, & Schwanenflugel, 1995; Schmitt & Sha, 2009; Van der Stel & Veenman, 2010; Veenman & Spaans, 2005; Veenman, Wilhelm, & Beishuizen, 2004). This growth of metacognitive skills persists well into adulthood (Veenman et al., 2004; Weil et al., 2013). At all ages, however, huge individual differences in metacognitive skills can be observed in same-age learners, indicating a differential developmental pace of metacognitive skills (Van der Stel & Veenman, 2014; Veenman et al., 2004).

Until the age of 14, children's metacognitive skills have a substantial domain- or task-specific orientation. Learners may vary in metacognitive skills they apply to reading, problem-solving, or discovery-learning tasks (Van der Stel & Veenman, 2010; Veenman & Spaans, 2005). Veenman and Spaans (2005, p. 172) argued that: "…metacognitive skills may initially develop on separate islands of tasks and domains that are very much alike". Beyond the age of 14, however, metacognitive skills merge into a generalized repertoire across tasks and domains. In a longitudinal study, Van der Stel and Veenman (2014) followed 13-year-olds for three successive years as they performed a reading task in history and a problem-solving task in mathematics each year. Between the ages of 13 to 14 years, children's metacognitive skills for both tasks improved, but growth leveled off between 14 to 15 years. At the same time, metacognitive skills shifted from being partly task or domain-specific to becoming entirely general by the age of 15. Principal-component analysis on metacognitive-skill measures for both tasks extracted a general component along with a weaker domain-specific component in the first two years. At the age of 15 years, however, only a strong general component remained. Van der Stel and Veenman postulated that this qualitative change into a generalized repertoire of metacognitive skills goes at the expense of a temporary halt in metacognitive growth. Beyond the age of 15, growth is expected to resume (Veenman et al., 2004) and learners have a personal repertoire of metacognitive skills at their disposal that they tend to apply to any new task (Schraw, Dunkle, Bendixen, & Roedel, 1995; Schraw & Nietfeld, 1998; Veenman & Beishuizen, 2004; Veenman, Elshout, & Meijer, 1997; Veenman & Spaans, 2005; Veenman & Verheij, 2003; Veenman et al., 2004). Van der Stel and Veenman (2014), however, could not establish such resumed growth in general metacognitive skills, as their study did not include measurements beyond the age of 15. Therefore, a first objective of the present study is to find additional support for a pause or decline in metacognitive growth around the age of 14 to 15, with a continuation of growth at the age of 16.

Gender Differences in Development

Results from studies are not conclusive with regard to gender differences in metacognition. Some studies revealed gender effects in self-reported metacognitive regulation, with girls surpassing boys in the age of 9 to 18 years (Ablard & Lipschultz, 1998; Leutweiler, 2009; Mok, Fan, & Pang, 2007; Zimmerman & Martinez-Pons, 1990). Wolters and Pintrich (1998) obtained gender differences in favor of girls for self-reported cognitive-strategy use in 12- to 13-year-olds, but not for self-regulation. Moreover, Hong, Peng, and Rowell (2009) did not find any gender effects in the self-reported metacognitive regulation of children, aged 12 and 16 years. Mixed evidence is also found in studies that assessed the actual use of metacognitive skills during task performance. In a study of Bardos, Naglieri, and Prewett (1992), girls outperformed boys in the age of 7 to 15 years on a planning task, whereas Otero, Campanario, and Hopkins (1992) did not find gender differences for 15- and 17-year-olds with a comprehension-monitoring task.

Evidence of gender-age interactions in metacognitive skills is scarce. Only Leutweiler (2009) reported that initial gender differences in self-reported monitoring and evaluation at the age of 15 years were fading out when learners reached the age of 18 years. Detailed inspection of the Van der Stel and Veenman (2014) data suggested that the pause in metacognitive growth occurs in females at the age of 13 to 14, while it is delayed in males to the age of 14 to 15. This gender-age interaction, however, could not be statistically tested due to an insufficient number of participants. Multiple assessments of metacognitive skills from thinking-aloud protocols in a longitudinal design did not allow for a large sample. Therefore, the second objective of the present study is to further explore gender differences in developmental pace. If female young adolescents are precocious in the development of metacognitive skills, relative to male adolescents, then a gender-age interaction may be expected in metacognitive skills. Female adolescents would show ceased and resumed metacognitive growth one year ahead of male adolescents.

Assessment of Metacognitive Skills

Detecting a complex gender-age interaction would require an alternative assessment instrument that is easy to administer in large groups and less time-consuming than the analysis of think-aloud protocols. For that reason, many researchers resort to self-report instruments, such as questionnaires (e.g., MAI, Schraw & Dennison, 1994; MSLQ, Pintrich & De Groot, 1990). Self-reports of metacognitive skills, however, suffer from serious validity problems (Veenman, 2011). Self-reports do not correspond with the learner's actual metacognitive skills during performance on an appropriate task (Bannert & Mengelkamp, 2008; Cromley & Azevedo, 2006; Hadwin, Nesbit, Jamieson-Noel, Code, & Winne, 2007; Veenman, 2005; Veenman, Prins, & Verheij, 2003; Winne & Jamieson-Noel, 2002). Learners do not do what they previously said they would do, nor do they accurately recollect what they have recently done. Self-reports need to be reconstructed from memory by the learner and, consequently, they are subject to memory failure, distortion, and interpretive reconstruction (Veenman, 2011). Adequate assessment of metacognitive skills relies on online assessment methods that are administered during actual task performance. Typical online methods are observations and the analysis of think-aloud protocols. With online methods, actual learner behavior is coded on externally defined criteria by external agencies, such as 'blind' judges and observers (Veenman, 2011).

Recently, the online method of tracing metacognitive behaviors of learners in computer logfiles has made its entry (Veenman, 2013; Veenman, Bavelaar, De Wolf, & Van Haaren, 2014; Veenman et al., 2004; Winne, 2010). A learning task is presented on a computer, while learner activities are recorded in a logfile and automatically coded according to a coding scheme. The advantage is that several learners can work simultaneously on their individual computer in the classroom, during which data are unobtrusively collected. In the present study, the Otter task will be used, which is a computer-based environment for inductive learning (Veenman et al., 2004; cf. De Jong & Van Joolingen, 1998). Previously, logfile assessments of metacognitive skills with the Otter task have been validated against think-aloud measures (Veenman, 2013; Veenman et al., 2014). The third and last objective of the present study is to establish whether logfile assessments are sensitive enough to capture metacognitive developmental processes, in particular gender-age interactions.

Method

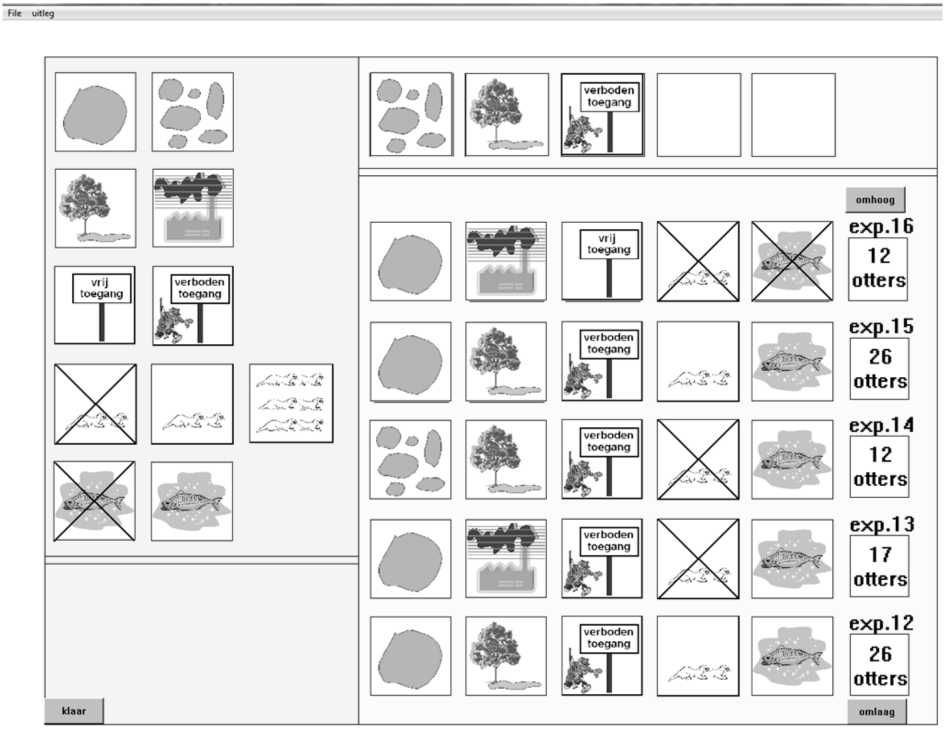
Participants

Secondary education in the Netherlands has a separate track for pre-academic education. Participants in this study with a cross-sectional design were 119 students from all second, third, and fourth classes of the pre-academic track from two sub-urban secondary schools. The second-class group included 29 males and 19 females (mean age 13:9 yrs.), the third-class group concerned 17 males and 19 females (mean age 14:10 yrs.), and the fourth-class group consisted of 20 males and 15 females (mean age 15:9 yrs.). Informed consent was given by their parents.

Measures

Learning environment – a computerized learning-by-discovery task was adapted from Veenman et al. (2004) and implemented in Authorware, an authoring environment for PC. The Otter task was originally developed by Wilhelm, Beishuizen, and Van Rijn (2001), but task difficulty was increased in order to meet with the higher level of pre-academic secondary-school students (Veenman et al., 2014). During the Otter-task, participants have to discover the (combined) effects of five independent variables on the growth of the otter population by performing experiments. The five variables are habitat (either one big area, or separated small areas), environmental pollution (either natural clean or polluted), public entrance (either no entrance or free entrance), setting out new otter couples (none, one couple, or more couples), and feeding fish in wintertime (yes or no). Independent variables may have no effect on the otter population (public entrance), a main effect (habitat; pollution), and interact with another variable (habitat x setting out otter couples; pollution x feeding fish). In each experiment, participants choose a value for the five variables by clicking on the pictograms on the left, and then request the computer to calculate the growth of the otter population (see Figure 1). Results of experiments done are transferred to a storehouse on the right and participants can scroll up and down the storehouse to consult earlier results. After a minimum of 15 experiments, an exit button becomes visible which allows participants to leave the learning environment. Participants, however, are free to continue with further experimentation. This minimum number of experiments has been set to ensure that enough data will be available for assessing all indicators of metacognitive skills from the logfiles (see below).

Figure 1. *Interface of the Otter Task*



Metacognitive skills – all actions are logged in a text file, which logfile is automatically scored on various metacognition measures by the computer (see Table 1). The total number of experiments performed by the participant (Number.exp) is recorded as a positive indicator of metacognitive skillfulness. The higher the number of experiments, the more complete experimentation is expected to be. Evaluation and elaboration of outcomes may incite participants to do additional experiments. Secondly, the time elapsed between receiving the outcome of a former experiment and taking action in the next experiment (Think-time) is registered in seconds as a positive indicator of outcome evaluation, reorientation, and planning of the next experiment. Think-time is accumulated over the experiments. Thirdly, the frequency of scrolling down to earlier experiments (Scrolldown) and scrolling back up (Scrollup) is assessed as a positive indicator of metacognitive skillfulness. Scrolling indicates a participant's intention to check earlier experimental configurations or to relate the outcomes of experiments. To avoid skewness in distribution of scores due to outliers, a square-root transformation is applied to Scrolldown and Scrollup. A fourth logfile indicator concerns the number of variables changed between two subsequent experiments. Varying only one variable at a time in transitions between experiments (VOTAT;

Chen & Klahr, 1999; Tschirgi, 1980) is a positive indicator of planning and systematical execution of experiments. Thus, the number of transitions between experiments with the value of only one variable being altered (Votat.pos) is registered as a positive indicator of metacognitive skillfulness. The mean number of variables changed per experiment minus one (Votat.neg) is also obtained for each participant, however, as a negative indicator of metacognitive skillfulness (Veenman et al., 2004). If more than one variable is changed between experiments, one cannot attribute the differences in outcomes to any of the changes in variables made. As a fifth indicator, the number of unique experiments performed (Unique.exp) out of 48 possible unique experiments is taken as a positive indicator for coverage of the experiment space (Klahr, Fay, & Dunbar, 1993). Metacognitively proficient learners tend to keep track of potential experiments to be done and plan their experiments accordingly. These logfile indicators of metacognitive skillfulness have been validated against think-aloud measures in earlier studies. Correlations between composite logfile scores and overall think-aloud measures of metacognition were .84 (Veenman et al., 2004) and .96 (Veenman, 2013). Think-time has been added later to logfile registration, but proved to fit in with the other indicators (Veenman et al., 2014).

Table 1. *Labels and Descriptions for Logfile Measures*

Label	*Description*
Number.exp	Total number of experiments performed
Thinktime	Time in sec. elapsed between receiving the outcome of a former experiment and the first move in the next experiment, accumulated over the experiments
Scrolldown	Frequency of scrolling down to earlier experiments
Scrollup	Frequency of scrolling back to later experiments
Votat.pos	Number of transitions between experiments in which only one variable is altered
Votat.neg	Mean number of variables changed in transition between experiments, minus one
Unique.exp	Number of unique experiments performed out of 48 possible unique experiments

All scores on the seven measures are standardized into *z*-scores and the sign of Votat.neg is inverted in order to make it a positive indicator. To avoid overweighing Scrolling and Votat, mean *z*-scores are calculated for Scrolling over Scrolldown and Scrollup, and for Votat over Votat.pos and Votat.neg. Finally, mean *z*-scores are calculated over the five indicators as an overall measure of metacognitive skillfulness (MS, with Cronbach's alpha = .70).

Learning performance – in order to avoid confounding assessments of metacognition and learning performance, a separate measure of learning performance is administered afterwards with a Multiple-choice (MC) posttest of 20 items. All questions pertain to knowledge-based reasoning about the (combined) effects of independent variables on the otter population. For instance, an MC-item is: "In an environmental restructuring plan, separated areas become interconnected. Which other intervention from the restructuring plan would have a positive effect on the otter population as a result of that enlarged area? a) fighting pollution, b) limiting public access, c) setting out new otter couples, d) stop feeding fish." The correct answer is c. Correct MC-items yield one point each, with a maximum total score of 20. Cronbach's alpha is .40 for all participants, .31 for males only, and .50 for females only. Alphas are relatively low due to item difficulty, but MC-test scores allow for substantial variation among participants (see below).

Procedure

Participants individually work on a computer in the classroom with the Otter task. Paper and pen are provided for making notes if participants prefer to do so. The Otter task starts with an introduction of the independent and dependent variables, and participants are instructed to discover single and combined effects of independent variables on the otter population by performing experiments. Moreover, participants are informed that they will be tested for their knowledge about these effects afterwards. After finishing the Otter task, notes are taken away and the posttest with MC-questions is presented on the computer. Participants are told beforehand that they are not allowed to leave class once they are ready, in order to refrain them from rushing through the Otter task. There was a practical time limit of one hour, but all participants managed to perform the Otter task and answer the MC-questions in due time.

Results

Descriptives

First, descriptives are given for the raw scores on the seven metacognition measures obtained from the logfiles, as well as for MC Learning performance (see Table 2).

Table 2. *Descriptives for Raw Logfile Measures and Learning Performance*

Variable	*M*	*SD*	Min	Max
Logfile Measures				
Number.exp	17.24	3.98	15	41
Thinktime	169.94	58.40	52	399
Scrolldown	7.29	9.29	0	53
Scrollup	4.39	5.90	0	26
Votat.pos	4.18	3.36	0	18
Votat.neg	21.64	7.75	4	43
Unique.exp	14.03	2.49	6	24
MC Learning Performance	6.75	2.48	1	13

Analyses of Overall Logfile Measure for Metacognition

ANOVA was performed on MS with Class (2, 3, and 4) and Gender (male, female) as between-subjects variables. Neither the main effect of Class [$F(2,113)=2.03$], nor the main effect of Gender [$F(1,113)=1.06$] appeared to be significant. The interaction effect of Class x Gender, however, was significant with $F(2,113)=3.30$ ($p<.05$, $\eta^2=.06$). MS of male participants declined in the third class and recovered in the fourth class, whereas females started lowest in the second class, improved in the third class, and peaked in the fourth class (see Table 3).

Table 3. *Means (and SE) for Logfile Metacognition (Metacognitive Skillfulness - MS)*

MS	Class 2	Class 3	Class 4	Total Gender
Males	.16	-.37	-.07	-.09
	(.18)	(.24)	(.22)	(.12)
Females	-.27	-.03	.59	.10
	(.23)	(.23)	(.25)	(.14)
Total Class	-.06	-.20	.26	
	(.14)	(.16)	(.17)	

Analyses of Learning Performance

ANOVA was performed on MC Learning performance with Class (2, 3 and 4) and Gender (male, female) as between-subjects variables. There was a main effect of Class with $F(2,113)=7.70$ ($p=.001$, $\eta^2=.12$). Post-hoc comparisons (Tukey HSD, Scheffé, and LSD) were significant for class 2 vs. 4 ($p<.01$) and class 3 vs. 4 ($p<.01$), but not significant for class 2 vs. 3. Learning performance increased with age, especially in the fourth class (see Table 4). Neither the effect of Gender [$F(1,113)=0.05$], nor the interaction effect of Class x Gender [$F(2,113)=0.26$] appeared to be significant.

Table 4. *Means (and SE) for Multiple-choice (MC) Learning Performance*

MC	Class 2	Class 3	Class 4	Total Gender
Males	6.24	6.06	8.00	6.77
	(.44)	(.58)	(.53)	(.30)
Females	5.95	6.53	8.13	6.87
	(.54)	(.54)	(.61)	(.33)
Total Class	6.09	6.29	8.07	
	(.35)	(.40)	(.41)	

Correlation between Logfile Metacognition and Learning Performance

The correlation between MS and MC Learning performance was .29 (p<.01) for the entire group of 119 participants. For participants from 2nd, 3rd, and 4th class, correlations were .16 (n.s.), .37 (p<.05), and .37 (p<.05), respectively. For male and female participants, correlations were .19 (n.s.) and .39 (p<.01), respectively.

Discussion

The first research question concerned the occurrence of a pause or decline in the growth of metacognitive skills between the age of 14 years (class 2) and 15 years (class 3), accompanied by resumed growth at the age of 16 (class 4). ANOVA on the MS data did not reveal a significant main effect of Class. Although results more or less show a decline in class 3 and resumed growth in class 4, differences between age groups were not sufficiently substantial to indicate a stable pause or decline in growth of *all* participants between the age of 14 and 15 years. As such, the present results do not corroborate the findings of Van der Stel and Veenman (2014). The main effect of age, however, was suppressed by differential developmental patterns for males and females.

The second research question pertained to a gender-age interaction in metacognitive skills. Female participants were expected to show a pause or decline in growth and a subsequent resumption of growth one year ahead of male participants. ANOVA on the MS data yielded a significant gender by age interaction, much in line with the expectations. Females started out low in class 2, recovered in class 3, and finally peaked in class 4. Males, on the other hand, started positive in class 2, declined in class 3, and recovered in class 4. Although data neither included females in class 1, nor males in class 5, the pattern of means in Table 3 shows that females are running one year ahead of males between the ages of 14 to 16 years. Females in class 2 score similar to males in class 3, while females in class 3 attained scores similar to males in class 4. This gender-age interaction can be interpreted as a refinement of the findings of Van der Stel and Veenman (2014). A pause in metacognitive growth may occur, albeit at the age of 13 to 14 in females and at the age of 14 to 15 in males, which pause is followed by recovery or resumed growth. Thus, the metacognitive development of male young adolescents follows the pattern of female development with a delay of one year. Beyond the age of 16, male adolescents will likely catch up with females, as research by Leutweiler (2009) indicated that initial gender differences in metacognition at the age of 15 faded out in the years thereafter.

The present study cannot give a decisive answer about whether such a pause or decline in metacognitive growth reflects a trade-off with the transition from (partly) domain-specific to entirely general metacognitive skills. Van der Stel and Veenman (2014) obtained evidence in favor of such a transition during a pause in metacognitive growth. The transition to general metacognitive skills fits in with the time frame proposed by Fisher and Silvern (1985), who postulated eight consecutive developmental levels. The last level of cognitive development is "Relations of abstract generalizations", which emerges at the age of 14 to 16 years. It allows children to deal with complex relations among abstractions and successfully complete most formal-operations tasks. Decontextualizing metacognitive skills to a general, task- and domain-surpassing repertoire requires the formation and organization of abstractions. This generalization process could not be investigated in the present study, as a single task was presented to all participants in a cross-sectional design. Van der Stel and Veenman (2014) contrasted text studying in history with mathematical problem solving in a longitudinal design. Each year, new tasks were presented to participants, with a difficulty level aligned to their age. Although these age-appropriate tasks were ecologically valid, they were not identical over age. The advantage of cross-sectional designs is that the same tasks can be administered to various age groups (Schraw et al., 1995; Veenman & Spaans, 2005). Therefore, an agenda for future research would be to replicate the present study, extended with logfile analyses of an entirely different task (such as reading text with gStudy; Hadwin et al., 2007).

Results for MC Learning performance do not follow the gender-age interaction obtained in the metacognition data. The significant main effect of Class particularly emphasized the improved learning performance of all fourth-class participants. First, it should be acknowledged that learning performance is not exclusively moderated by metacognitive skills (Veenman, 2008). Moreover, the reliability of the MC questionnaire was relatively low, which suppressed correlations with MC Learning performance (cf. Veenman et al., 2014). Metacognitive growth resumed earlier in female participants, which could have resulted in the more reliable measure of MC Learning performance and the higher correlation with metacognitive skills for females, relative to male participants. Perhaps, the transition to general metacognitive skills temporarily interfered with the process of knowledge acquisition during task performance. Thus, improved learning performance in the fourth class could designate the strength of the general metacognitive repertoire at the age of 16.

The third objective of this study was to establish whether logfile assessments capture developmental processes in metacognitive skills. Results show that logfile assessments with the Otter task were sufficiently fine-grained to detect a complex gender-age interaction in metacognitive skills. When logfile measures are validated against other online methods, they may represent a broad array of metacognitive skills (Veenman, 2013; Veenman et al., 2014). The importance of validation can hardly be overestimated. Logfile assessments merely produce measures of actual behavior, for which the underlying metacognitive motives need to be inferred. Only through validation, a researcher can certify that, for instance, a particular button press in the computer-based learning environment represents a metacognitive skill, rather than being an arbitrary activity (Winne, 2010). Thus, every new learning environment requires additional validation of logfile assessments. In the same vein, logfile assessments of developmental pace in metacognition should be calibrated. The present study shows that logfile assessments with the Otter task have discriminative validity for detecting developmental changes in the metacognitive skills of 13- to 16-year-olds. Consequently, the Otter task is a proper instrument for research into the metacognitive development of young adolescents, for instance, when investigating the relation between metacognitive and executive skills over age (Fernandez-Duque, Baird, & Posner, 2000). Assessments of metacognitive development in other age groups, however, would still require additional validation of the Otter task.

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