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RESEARCH ARTICLE

A lifespan perspective on decision-making: A cross-sectional comparison of middle childhood, young adulthood, and older adulthood

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Abstract

Study 1 contributes to the sparse empirical research on decision-making across the lifespan by presenting a direct comparison of middle-aged children's ($N = 40$; fourth grade), younger adults' ($N = 40$; 20–39 years), and older adults' ($N = 40$; 62–82 years) adaptive decision-making. Participants played a non-probabilistic, multi-attribute, information-board decision game and completed a verbal skill test (serving as an indicator of crystallized intelligence). Information search and choices were analyzed for two task structures (manipulated within-subjects; few vs. many relevant information-dimensions). The competence to adapt search to the task structure was found from middle childhood to older adulthood. Also, participants of all age groups made comparably good, informed choices. Thus, results highlight similarities in decision-making across a wide age range. Still, we observed distinct patterns on the process level. Older adults demonstrated difficulty in ignoring irrelevant information and searched an overly extensive information subset. In contrast, children showed an information-frugal approach that was widely similar to younger adults. A reanalysis of Study 1's data and previous studies ($N = 228$) expands the child sample from third to sixth grade. It supports our main findings and suggests developmental improvement across childhood. In Study 2, we used a metacognition questionnaire to investigate the role of crystallized intelligence that might be a compensation mechanism for older adults ($N = 63$). We discuss implications for adaptive decision-making models.

KEYWORDS

adaptive decision-making, aging, child decision-making, development of decision-making, information-board

1 | INTRODUCTION

How do we make good decisions in today's world of infobesity, where even purchasing a coffee-to-go can mean choosing from more than

87,000 possible options (Arthurs, 2009)? According to Herbert Simon's traditional notion of bounded rationality, we rarely base our decisions on all potentially available information but instead often use simple strategies that consider only the most important information

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(Simon, 1955). The cornerstone of the following multi-strategy models of decision-making, both traditional and contemporary ones (e.g., Gigerenzer & Gaissmaier, 2011; Payne et al., 1988), is the assumption of ecological rationality (Gigerenzer & Goldstein, 1996). That is, individuals can maintain a high level of decision accuracy by switching strategies contingent on the decision environment (e.g., task structure), thus making use of information-frugal strategies. For example, consider the task structure of a decision between several washing machines. If you find multiple information-dimensions such as price, brand, and capacity to be similarly relevant, an information-intense procedure that evaluates each option on multiple dimensions in a compensatory manner would be appropriate (weighted-additive strategy: choose the option with the highest weighted value integrated across all information-dimensions; e.g., Payne et al., 1988). However, if your main goal when purchasing a machine is to spend as little money as possible, it would be sufficient to limit your information search to price—comparing machines on other, less relevant dimensions such as brand would not be necessary (lexicographic strategy: choose the option with the highest value on the most relevant dimension; continue onto the next dimension only if decision options do not differ on the previous dimension; e.g., Payne et al., 1988). Adaptive decision-making (ADM)—that is, changes in decision behavior based on characteristics of the decision task—has been extensively studied with participants in young adulthood. A standard tool for investigation is the information-board paradigm that provides decision-related information in an initially covered matrix (e.g., Payne et al., 1988; see also multi-attribute decision matrix, Mouselab). Participants' information search patterns of the matrix can be interpreted as an indicator of the applied strategy (Norman & Schulte-Mecklenbeck, 2010). For example, in tasks with little relevant information, an adaptive decision maker should apply an information-frugal procedure—that is, search less information—compared with tasks with much relevant information. Over the years, a large body of research has demonstrated that younger adults proficiently adapt to the task structure (e.g., Payne et al., 1988; overview: Bröder, 2003). This manuscript takes a lifespan perspective on ADM from middle childhood to old age.

Multi-strategy models conceptualize decision-making as a multi-stage process. Key stages include the selection and execution of decision strategies (e.g., Beach & Mitchell, 1978; see building blocks: Gigerenzer & Gaissmaier, 2011). Although formulated as a universal mechanism, developmental changes in cognitive resources across the lifespan can affect these stages in various ways (see, e.g., Gigerenzer, 2003; Löckenhoff, 2018 for conceptual frameworks). For example, changes in processing speed and working memory can affect how successfully decision makers integrate information (Fechner et al., 2019; Löckenhoff, 2018). Cognitive resources associated with fluid intelligence are assumed to set an upper limit to the cognitive effort that a decision maker can invest during strategy execution (Mata et al., 2007; Mata et al., 2011). In line with this, research on ADM in older adults assumes that age-related decline impairs strategy execution, especially the execution of information-intense, complex strategies (Bruine de Bruin et al., 2016; Mata et al., 2012).

Ample empirical evidence supports this notion, showing that older adults search less information compared with younger adults (e.g., Jin et al., 2019; Johnson, 1990; overview: Mata & Nunes, 2010), prefer simple strategies (e.g., Bruine de Bruin et al., 2016; Johnson, 1990; Mata et al., 2007; Pachur et al., 2009; Queen et al., 2012), and demonstrate less accurate strategy execution (Bruine de Bruin et al., 2012; Del Missier et al., 2017; Fechner et al., 2019; Mata et al., 2010; Rosi et al., 2019). In children, this area of research has received less attention (but see Bereby-Meyer et al., 2004), although cognitive maturation across childhood (e.g., Diamond, 2013) would suggest similar patterns in younger children. Research on ADM in children addresses the ability to selectively focus on relevant information. Since information-frugal strategies require individuals to ignore irrelevant information and prioritize relevant information, age-related changes in this ability may impair their execution (Mata et al., 2011). Indeed, predominant findings in child decision research indicate that children search information in a less systematic manner and less successfully ignore irrelevant information throughout the elementary school years (e.g., second grade: Davidson, 1996, Lindow & Betsch, 2018; third grade: Betsch et al., 2016, Lindow & Betsch, 2018, 2019; fourth grade: Mata et al., 2011). Decision-making behavior in children begins to mirror that of adults around sixth grade (Klayman, 1985; Lindow & Betsch, 2018; Mata et al., 2011). In older adults, this aspect has not yet been thoroughly researched (for mixed empirical evidence, see Queen et al., 2012); however, cognitive decline in the ability to suppress irrelevant information would suggest a similar pattern as that observed in children (Löckenhoff, 2018).

Whereas the aforementioned cognitive impairments should similarly affect decision-making in children and older adults, older adults can potentially compensate for such impairments with higher levels of crystallized intelligence. Crystallized intelligence generally increases with age (Salthouse, 2004). Broader knowledge and experience might benefit strategy execution as well as strategy selection (see Löckenhoff, 2018, for a discussion). For example, crystallized intelligence has been linked to a better understanding of the fit between the task structure of the decision and specific strategies (Mata et al., 2007; see also Bröder, 2003). This might counteract impairments in strategy selection and preserve ADM in older adults.

To date, developmental ADM studies investigated either developmental patterns across adulthood (overviews: Mata et al., 2015; Mata & Nunes, 2010) or developments across childhood (e.g., Bereby-Meyer et al., 2004; Betsch et al., 2016; Davidson, 1996). Consequently, methodological approaches in the two domains differ substantially. An exception is the research project of Mata and colleagues. They used comparable information-board procedures and measures in both their adulthood studies (Mata et al., 2007; Mata et al., 2010) and a child study (Mata et al., 2011). Findings show developmental improvements across childhood (fourth grade vs. sixth grade vs. younger adults) and decline in older adults with regard to selecting decision strategies from feedback. In addition, their study-battery highlights a crucial challenge for life-span investigations. In their feedback-learning tasks, participants in all age groups showed unexpectedly extensive, almost exhaustive, information search (Mata

et al., 2010, 2011). In a very similar information-board procedure without feedback-learning, Mata et al. (2007) report the standard finding of reduced information search in older adults compared with younger adults. This indicates that even minor task features might moderate the impact of age-related factors on decision-making (Löckenhoff, 2018; Mata et al., 2015; Salthouse, 2004) and challenges the validity of conclusions drawn from age comparisons across different studies (Levin et al., 2014). The current state of the literature makes it difficult to integrate empirical findings into a life-span perspective and reveals the need for studies that track decision-making across a broader age range (for lifespan studies with risk tasks, see, e.g., Beitz et al., 2014; Weller et al., 2011).

1.1 | Overview of the current research

To address this research gap, in Study 1, we applied an age-neutral decision game to directly compare children and older adults with younger adults, who serve as a benchmark for competent ADM (e.g., Bröder, 2003; Payne et al., 1988). We investigate ADM in older adults above 60 years of age, younger adults below 40 years, and middle-aged children (fourth grade). The selection of age groups is comparable with Mata et al. (2010, 2011), with the exception that we did not include an additional sample of older children in Study 1, who had performed similar to adults in Mata et al.'s study. We used the Piggy-Bank-Task, a preferential multi-attribute decision task that has been applied to date to investigate child decision-making in comparison with young adults (Lindow & Betsch, 2018, 2019). It requires the decision maker to search, weight, and integrate multiple pieces of information. In addition, the task structure can be manipulated in order to assess decision makers' ADM—including the cognitive ability to focus on relevant information (for a discussion, see Lindow & Betsch, 2019). Due to age-related changes in these cognitive resources, older adults are generally expected to show impaired ADM similar to children. Previous research with the Piggy-Bank-Task suggests an information-frugal approach in children that impairs performance as long as children have difficulty systematically focusing on relevant information (Lindow & Betsch, 2018, 2019). However, in contrast to children, higher crystallized intelligence might compensate for older adults cognitive decline (Löckenhoff, 2018; Mata et al., 2007). To further explore this issue, we included an indicator of crystallized intelligence in addition to decision-making measures in Study 1 (verbal skill test; see Howse et al., 2003; Mata et al., 2007, for a similar procedure).

Study 2 further explores the role of crystallized intelligence. It addresses the idea that older adults with higher crystallized intelligence might have a superior representation and understanding of the task structure.

Finally, we report a reanalysis. We combined our data of Study 1 with previous research using the same procedure (Lindow & Betsch, 2018, 2019, children from third to sixth grade) in order to provide the most comprehensive and accurate representation of lifespan development as possible given the current empirical basis.

2 | STUDY 1

2.1 | Method

2.1.1 | Participants and design

Forty-one children (46% female, years of age: $M = 9.27$, $SD = 0.55$, range: 8–10, fourth-grade), 40 younger adults (65% female; $M = 27.00$, $SD = 6.69$, range: 20–39), and 40 older adults (48% female; $M = 69.22$, $SD = 5.81$, range: 62–82) participated. The study used a 3 (age group: children vs. younger adults vs. older adults) \times 2 (task structure: few vs. many relevant information-dimensions; within-subjects) factor design.

Participants share a middle-class socioeconomic background with German as their native language. Adults were community volunteers recruited in leisure clubs. Children attended main-stream classes and were recruited from three elementary schools in Erfurt, a moderately large city in central Germany. The study was part of science days for schools at the University of Erfurt organized specifically for data collection purposes.

Data was collected in two waves because the initially collected data set ($N = 94$) only allowed for the analysis of larger effects with sufficient power. With the final sample, we aimed to achieve a total sample size of $N = 120$. This is based on a power-analysis for a medium effect size in a repeated-measures analysis of variance with $\alpha = .05$, $1 - \beta = .80$. The collection of the vocabulary scores was conducted in a Bachelor Psychology seminar and is only available for participants in the first data collection wave. Appendix A provides an overview of the data collection process.

Children stated informed consent. Adult participants and children's parents provided written informed consent. All participants received age-appropriate prizes contingent on choice performance (i.e., toys and stationary for children, mean value: approx. 2 Euros; homecare and stationary for adults, mean value: approx. 7 Euros). The project was approved by the ethics committee of the University of Erfurt.

2.1.2 | Material

The material is openly available on the OSF project page: <https://osf.io/4yaj3/>

Decision game: The Piggy-Bank-Task

We used the computer program of the Piggy-Bank-Task (Lindow & Betsch, 2018), where participants repeatedly choose one of three piggy-banks for shopping (choice options). Each decision task displays an initially covered 3 (options) \times 4 (information-dimensions) information-board-matrix (see Figure 1). Prior to choice, participants can search for information on the content of the piggy-banks by opening cells on the information-board. Specifically, each piggy-bank can contain up to four bags containing different amounts of play-money (information-dimensions). Each money-bag is comparable to a

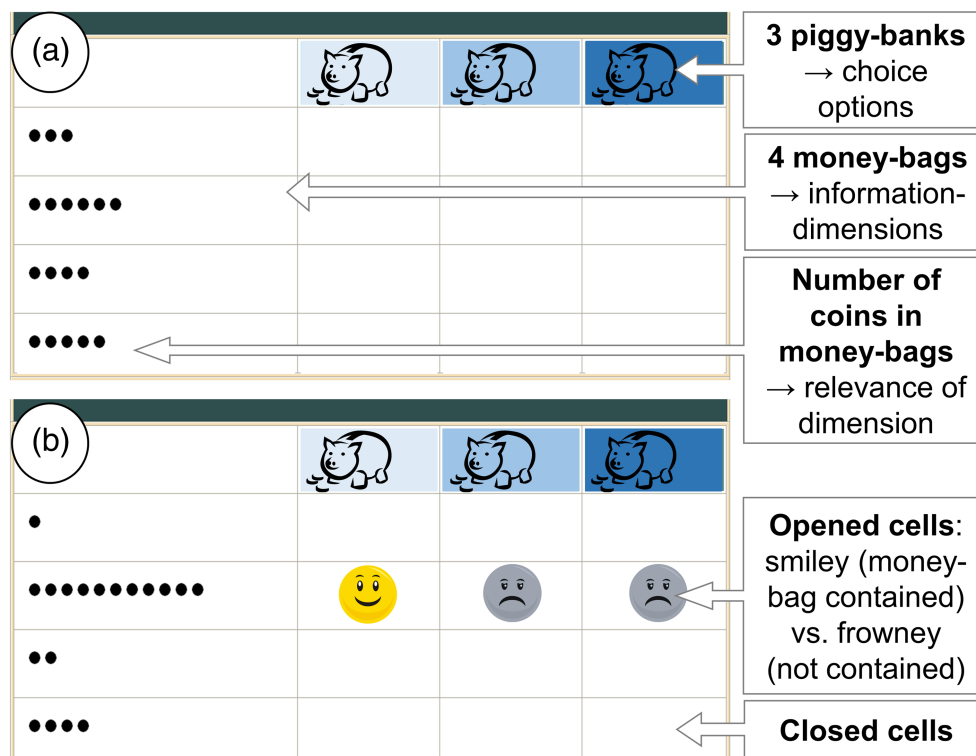


FIGURE 1 Information-board used in the Piggy-Bank-Task. Examples show (a) a task with many relevant information-dimensions and (b) a task with few relevant information-dimensions that differed in the dispersion of money-bag contents

bank-note that yields a certain amount of play-money. When participants open an information-board cell, a smiley or frowney appears, which indicates whether or not the money-bag is contained in the piggy-bank. Thus, via information search, participants can learn about the value of the choice-options. Prior to choice, participants can search as much information in whatever order they choose. To avoid memory influences, once opened, matrix cells remained opened until the decision was made.

Manipulation of task structure. The information-dimensions in the Piggy-Bank-Task differ in terms of their relevance for choice. Specifically, the number of coins contained in each money-bag corresponds to its relevance: That is, money-bags with a greater number of coins are more relevant than money-bags with smaller numbers of coins. Tasks with few and tasks with many relevant information-dimensions can be constructed by varying the dispersion of information relevance (Payne et al., 1988). As shown in Figure 1b, tasks with few relevant information-dimensions include one highly valuable, and thus relevant, information-dimension (money-bags: 11, 4, 2, and 1 coin). When one piggy-bank contains this most relevant money-bag and the others do not, this cannot be compensated by the remaining money-bags. In contrast, in tasks with many relevant information-dimensions, the money-bags are similarly filled and can possibly compensate each other (money-bags: 6, 5, 4, and 3 coins; Figure 1a). This task manipulation has been successfully applied with participants from 6 years of age onwards and is assumed to be applicable throughout adulthood (e.g., Lindow & Betsch, 2018, 2019).

Each participant completed one practice task followed by 10 decision tasks: five tasks each with many or few relevant information-

dimensions (same mixed order used for all participants; task list see Appendix B).

Verbal skill test

For children, we used the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 2015). Adults completed the Verbal Short Intelligence Test (VKI; Anger et al., 1980). Both tests apply a word-picture mapping procedure. Participants were asked to indicate one of four pictures that best matches the respective word. With adults, all 20 items of the VKI were used. For children, the PPVT was shortened to a maximum of 108 items.¹

2.1.3 | Procedure

Participants were tested individually in a separate cubicle at the university lab or a separate room at the respective facility. All participants performed the experiment under full attendance of a trained experimenter who provided all instructions verbally and operated the computer program. The procedure strictly followed Lindow and Betsch (2018, Experiment 1). In an explanation phase, the experimenter introduced the decision scenario of choosing piggy-banks filled with play-money. For demonstration purposes, real piggy-banks and money-bags were used. Then, the experimenter explained the information presentation by using a screen print-out of a fully opened information-board before showing the computer display of a closed information-board. Participants were instructed that it is not always necessary to open all cells of the information-board and that they can open as many cells as they like before choosing a piggy-bank. Before

beginning the test phase, participants played one practice task. At the end of the practice task, feedback was given—that is, the experimenter opened all information-board cells of the practice board and verbalized the content of the chosen piggy-bank by stating the amount of play-money coins contained therein.

In the subsequent test phase, 10 decision tasks directly followed one another without feedback. That is, the information-board immediately disappeared after the choice of a piggy-bank and was replaced by the next information-board. Unopened cells thus remained unopened. Participants indicated their next move in the game by pointing at the computer screen. At the end of the study, children completed a short questionnaire. Answers were used to check the manipulation of information relevance (i.e., that children attributed greater value to money-bags with more coins compared with money-bags with fewer coins; see Lindow & Betsch, 2018). Afterwards, a portion of participants completed a verbal skill test (see Appendix A for sampling). Finally, participants were debriefed and purchased prizes with the play-money coins they earned. The specific selection of prizes was not shown to participants until the end of the study.

2.2 | Results

2.2.1 | Overview of measures and data analysis

Participants' information search can be interpreted as an indicator of the applied strategy (Norman & Schulte-Mecklenbeck, 2010). Specifically, the overall amount of search indicates the intensiveness or frugality of a strategy. In addition, ADM can be inferred: An adaptive decision maker should search less information in tasks with few compared with tasks with many relevant information-dimensions. In the developmental context, the analysis of search amount should be accompanied by an evaluation of the searched information sample in terms of quality and selectivity (Lindow & Betsch, 2018). Merely adapting search amount does not guarantee a good sample of information unless

information relevance is considered. We thus assessed a set of decision-making measures: choice quality (i.e., accuracy), search amount (i.e., the overall amount of information searched), search adaptivity (i.e., the difference in search amount between task structures), search quality (i.e., search of relevant information), and search selectivity (i.e., avoidance of irrelevant information).

To assess age effects, we conducted repeated-measures analyses of variances (ANOVA) for choice quality, search amount, search quality, and search selectivity with age group and task structure as independent variables. The calculation of each of these decision-making measures is explained at the onset of the respective results section. Search adaptivity is indicated in the ANOVA by a main effect of task structure on search amount. To consider search adaptivity in the analysis of the vocabulary scores, we calculated an index that resembles the difference in search amount between tasks with few and tasks with many relevant information-dimensions ($= \frac{\sum_{\text{many}} n_{\text{searched information}}}{\sum_{\text{few}} n_{\text{searched information}}}$). Scores greater than one indicate higher search adaptivity.

The data and analysis codes including a data dictionary are openly available (Lindow & Lang, 2021).

2.2.2 | Data reduction

One child failed the manipulation-check of information relevance and was excluded from data analysis (analyzed data set: $N = 120$, evenly distributed across age groups).

2.2.3 | Choice quality

We calculated choice quality as the percentage of correct choices over all tasks ($= n_{\text{correct choices}}/n_{\text{all choices}} * 100$). As evident from the high choice quality scores in Table 1, overall, more than three quarters of the decisions were correct for all age groups. Children, younger

TABLE 1 Means (standard deviations) for choice quality, search amount, search quality, and search selectivity in percent in Study 1

Task	Choice quality	Search amount	Search quality	Search selectivity
Children				
All	77 (19)	62 (26)	78 (24)	31 (13)
Many relevant	69 (24)	66 (27)	71 (27)	19 (9)
Few relevant	86 (21)	58 (26)	85 (22)	43 (18)
Younger adults				
All	84 (13)	61 (18)	84 (13)	25 (15)
Many relevant	84 (21)	70 (16)	81 (16)	13 (9)
Few relevant	85 (22)	53 (21)	87 (13)	36 (22)
Older adults				
All	79 (22)	74 (24)	84 (19)	36 (11)
Many relevant	79 (29)	80 (21)	84 (20)	23 (7)
Few relevant	80 (23)	68 (29)	83 (19)	49 (19)

Note: The difference in search amount between tasks with many and few relevant information-dimensions indicates search adaptivity.

adults, and older adults performed comparably well. Accordingly, no main effect of age was found (see Table 2). However, in contrast to adults, children's choice quality differs between the two task structures (main effect of task structure and age * task structure interaction effect, see Table 2). Specifically, children performed worse in tasks with many relevant information-dimensions compared with tasks with few relevant information-dimensions (see post-hoc tests on the interaction effect in Table 2).

2.2.4 | Search amount and search adaptivity

We calculated search amount as the searched percentage of the presented information ($= n_{\text{information searched}}/n_{\text{all information provided}} * 100$). As

evident from the descriptive statistics reported in Table 1, participants appropriately searched less information in tasks with few compared with tasks with many relevant information-dimensions. Thus, they showed search adaptivity (main effect of task structure, see Table 2). Age groups differed in terms of this ability (age * task structure interaction effect, see Table 2). Still, search adaptivity was found in all age groups. Younger adults adapted their search amount to the greatest extent. However, also older adults and children searched less information when it was task-appropriate, which demonstrates their search adaptivity (see post hoc tests to the interaction effect in Table 2).

Considering the search amount across all tasks, the main effect of age shows that age groups differed (see Table 2). Specifically, as shown in Table 1, younger adults and children searched approximately 60% of information, that is, a similarly small subset of information. In

TABLE 2 Effects of the ANOVAs with choice quality, search amount, search quality, and search selectivity as dependent variables and age group and task as independent variables in Study 1

	ANOVAs	Post hoc
Choice quality		
Age	$F(2, 117) = 1.37, p = .259, \eta^2_{\text{partial}} = .02$	ns ^a
Task	$F(1, 117) = 7.07, p = .009, \eta^2_{\text{partial}} = .06$	^b
Age * task	$F(2, 117) = 4.62, p = .012, \eta^2_{\text{partial}} = .07$	$t_{\text{children}}(39) = -4.23, p < .001, d = -0.67$ $t_{\text{younger}}(39) = -0.24, p = .812, d = -0.04$ $t_{\text{older}}(39) = -0.33, p = .740, d = 0.05$
Search amount		
Age	$F(2, 117) = 3.78, p = .026, \eta^2_{\text{partial}} = .06$	$t_{\text{children/younger}}(69.1) = 0.21, p = .834, d = 0.05$ $t_{\text{younger/older}}(71.1) = -2.66, p = .010, d = -0.63$ $t_{\text{children/older}}(78) = -2.07, p = .041, d = -0.47$
Task	$F(1, 117) = 91.58, p < .001, \eta^2_{\text{partial}} = .44$	^b
Age * task	$F(2, 117) = 4.30, p = .016, \eta^2_{\text{partial}} = .07$	$t_{\text{children}}(39) = 3.60, p = .001, d = 0.57$ $t_{\text{younger}}(39) = 7.89, p < .001, d = 1.25$ $t_{\text{older}}(39) = 5.14, p < .001, d = 0.81$
Search quality		
Age	$F(2, 117) = 1.32, p = .272, \eta^2_{\text{partial}} = .02$	ns ^a
Task	$F(1, 117) = 31.33, p < .001, \eta^2_{\text{partial}} = .21$	^b
Age * task	$F(2, 117) = 12.11, p < .001, \eta^2_{\text{partial}} = .17$	$t_{\text{children}}(39) = -5.56, p < .001, d = -0.88$ $t_{\text{younger}}(39) = -3.30, p = .002, d = -0.52$ $t_{\text{older}}(39) = 0.22, p = .829, d = 0.03$
Search selectivity		
Age	$F(2, 117) = 7.37, p < .001, \eta^2_{\text{partial}} = .11$	$t_{\text{younger/older}}(78) = -3.73, p < .001, d = -0.84$ $t_{\text{children/younger}}(78) = 2.11, p = .038, d = 0.48$ $t_{\text{children/older}}(78) = -1.75, p = .084, d = -0.40$
Task	$F(1, 117) = 307.16, p < .001, \eta^2_{\text{partial}} = .72$	^b
Age * task	$F < 1$	$t_{\text{children}}(39) = 10.86, p < .001, d = 1.72$ $t_{\text{younger}}(39) = 9.84, p < .001, d = 1.56$ $t_{\text{older}}(39) = 9.84, p < .001, d = 1.56$

Note: We used an alpha level of .05 in the ANOVAs but report exact p values when possible. Post hoc tests are independent-samples T tests and one-sample T tests, two-tailed, Bonferroni corrected $\alpha = .017$.

^aMain effect and all corresponding post hoc tests not significant.

^bComparison of two conditions, post hoc tests not necessary.

contrast, older adults looked up more than 70% of information, which is a comparatively extensive subset (see post-hoc tests on the main effect of age in Table 2).

2.2.5 | Search quality

To assess whether participants can search an information sample containing the relevant information, we calculated search quality as the percentage of the relevant information that was searched on average over all tasks ($= \frac{n_{\text{relevant information searched}}}{n_{\text{relevant information provided}}} * 100$). As shown by the high search quality scores in Table 1, all age groups searched a high percentage of the relevant information (no main effect of age, see Table 2). With more than three quarters of the relevant information, participants had a sound information basis for their decisions. Whereas older adults searched equally well in both task structures, task structure effects occurred in younger adults and children (see post hoc tests to the interaction effect in Table 2). For these age groups, it was easier to search all relevant information in tasks with few compared with tasks with many relevant information-dimensions. Accordingly, a main effect of task structure and an age * task structure interaction effect occurred for search quality (see Table 2).

2.2.6 | Search selectivity

To assess whether participants can search a frugal information sample that contains no irrelevant information, we assessed search selectivity by calculating the percentage of irrelevant information in the searched subset on average over all tasks ($= \frac{n_{\text{irrelevant information searched}}}{n_{\text{all information searched}}} * 100$). Higher scores indicate a larger proportion of irrelevant information and thus lower competence in terms of ignoring irrelevant information.

As shown by the search selectivity scores in Table 1, participant's information samples contained irrelevant information. However, the vast majority of the searched information was relevant. As indicated by a main effect of age on search selectivity, age groups differed (see Table 2). Specifically, as evident from Table 1, younger adults performed best. Only one quarter of the information they searched was irrelevant. Older adults, in particular, differed. Approximately one third of their searched information was irrelevant (see post-hoc tests on the main effect of age in Table 2).

2.2.7 | Vocabulary scores

The data of four children were excluded from data analysis due to errors in test implementation ($N = 90$, equally distributed across age groups). Following the standard analysis procedure of the VKI, we assessed the number of correct responses for the same set of items for all participants (VKI: items 1 to 20; PPVT: items 85 to 168, i.e., the 84 items that were completed by all participants).

Descriptive statistics in Table 3 show that older adults had higher vocabulary scores than younger adults, $t(58) = 4.20$, $p < .001$, $d = 1.10$. This is consistent with literature on aging (e.g., Salthouse, 2004). In older adults, all decision-making measures except search quality were significantly correlated with vocabulary scores. That is, older adults with higher vocabulary scores achieved higher choice quality, were more adaptive to the requirements of the task (search adaptivity), searched less information overall (search amount), and also searched less irrelevant information (search selectivity, see Table 3). In contrast, no such correlations were found for children and younger adults.

2.3 | Discussion

Findings indicate that all age groups searched a good subset of information, made high quality choices, and adapted their search to the task structure. However, older adults tended to apply a rather information-intense procedure, whereas children and younger adults were more frugal. That is, they made equally good choices but searched less information. Interestingly, older adults with lower crystallized intelligence—as indicated by lower vocabulary scores—demonstrated impaired ADM. Older adults with higher crystallized intelligence were more adaptive in search and maintained an information frugal procedure. These individuals might have a better understanding of the task structure, allowing them to maintain ADM. To further explore this notion, we investigate older and younger adults' insight into the task structure in Study 2.

3 | STUDY 2

3.1 | Method

3.1.1 | Participants

Thirty-two younger adults (75% female, years of age: $M = 22.57$, $SD = 2.51$, range: 19–32) and 31 older adults participated (68% female, $M = 69.48$ year, $SD = 6.90$, range: 57–81). Participants share a middle-class socioeconomic background with German as their native language. Younger adults were recruited in university seminars of different majors. Older adults were recruited at an open day at the University of Erfurt. Younger adults were better educated than older adults (42% with high-school diploma). Participants provided written informed consent and received prizes as payment (i.e., homecare und stationary, mean costs: approx. 7 Euros). Data collection was conducted in a Master Psychology seminar for class credit.

3.1.2 | Material and procedure

After gaining experience in the Piggy-Bank-Task, participants completed a metacognition questionnaire. We report results from two

questions that assessed participants' metacognitive task knowledge (Ball et al., 1994; Flavell, 1979). Participants viewed two pairs of screenshots of decisions from the Piggy-Bank-Task. In the first pair, the two tasks differed in their task structure: Both screenshots showed a 2 (options) × 3 (information-dimensions) matrix, one with many relevant information-dimensions (i.e., 3 of 3), the other with few relevant information-dimensions (i.e., 1 of 3). In the second pair, the two tasks differed in terms of information-board size: One screenshot showed a 2 × 3 matrix, the other a 3 × 6 matrix. Participants were asked to look carefully at each pair of screenshots and then (1) indicate where it would be more difficult to make a decision (response categories: task A, task B, or both equally) and (2) write down the difference between the tasks in their own words. Responses to the latter were

coded as correct when participants referred to varying differences in coins (i.e., the relevance of the information-dimensions) for the first pair of screenshots and to varying numbers of money-bags (i.e., information-dimensions) or piggy banks (i.e., options) in the second pair of screenshots.

3.2 | Results and discussion

More than half of the younger adults (59%) but only 27% of older adults stated that the task with many relevant information-dimensions is more difficult. More than half of the older adults (55%) but only 31% of younger adults reported that both tasks were equally

TABLE 3 Descriptive statistics of vocabulary scores and correlations between vocabulary scores and decision making measures in Study 1

	N	Mean (SD) [range]	Choice quality	Search amount	Search quality	Search selectivity	Search adaptivity
Children	30	75.10 (3.82) [66–81]	.19	.18	.25	-.06	.08
Younger adults	30	10.93 (2.98) [4–16]	-.03	.14	.04	.14	-.10
Older adults	30	14.37 (3.35) [8–19]	.33*	-.33*	-.22	-.32*	.45**

Note: Vocabulary scores (i.e., number of correct responses) range from 0 to 84 for children and from 0 to 20 for adults.
* $p < .05$. ** $p < .01$; one-tailed.

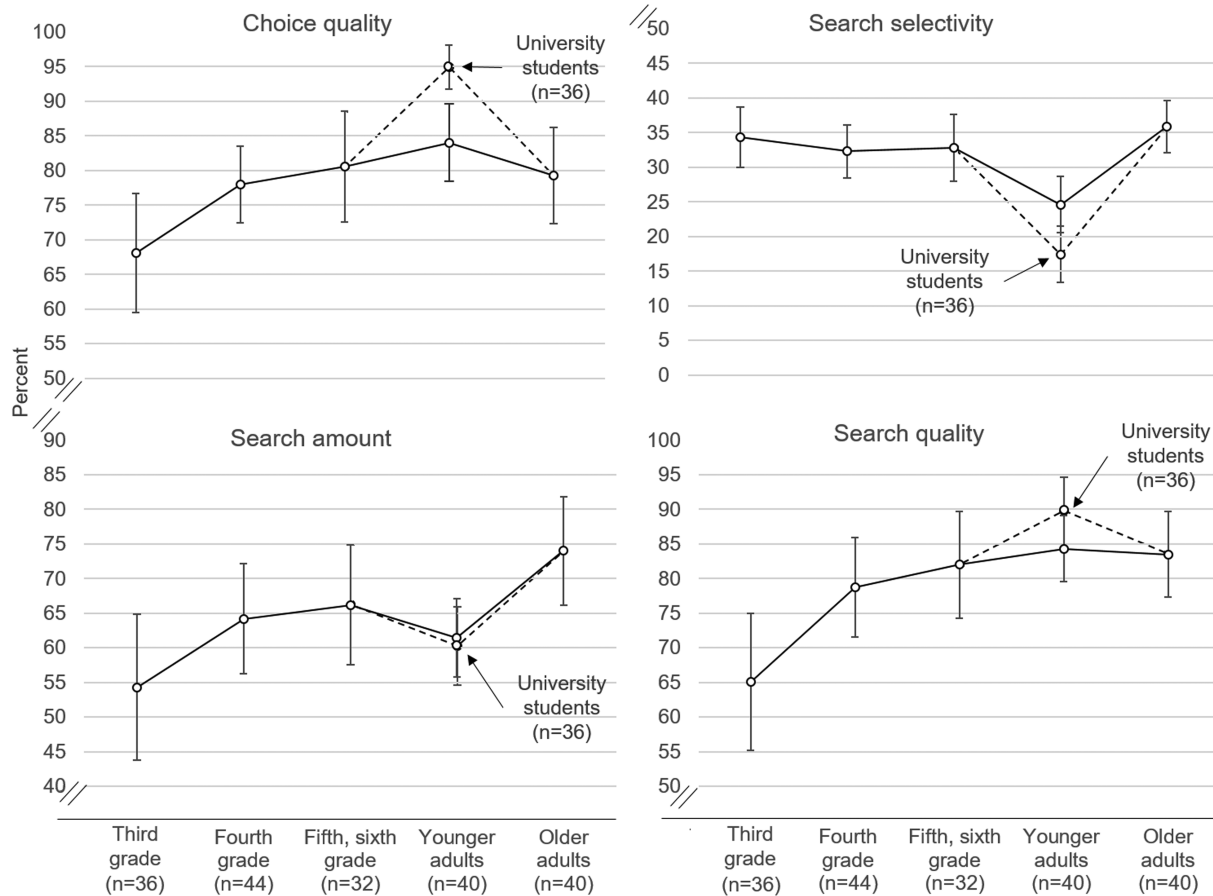


FIGURE 2 Means and 95% CIs of the decision-making measures in the Piggy-Bank-Task. The group positioned on top of the younger adults shows performance of the university student samples of Lindow and Betsch (2018, 2019). Note that although we used the same scale spacing for all plots, we display only a section of the full scale, which differs between plots depending on the location of the results

difficult. For complexity, we find a different pattern. The majority of younger (97%) and older adults (87%) correctly indicated that the larger information-board is more difficult (whereas 3% of younger adults and 7% of older adults assume equal difficulty). When asked to describe the difference between task structures, 91% of younger adults but only 36% of older adults correctly referred to differences in the amount of relevant information. Again, for complexity, results are more similar between the two age groups: the vast majority, that is, 94% of younger adults and 82% of older adults, correctly referred to board size. This suggests that, in contrast to younger adults, for many older adults task structure is not a recognized, noteworthy task difference. At the same time, older adults more often recognized variations in visually salient aspects of the task such as information-board size.

4 | REANALYSIS OF STUDY 1 WITH DATA FROM LINDOW AND BETSCH (2018, 2019)

Lindow and Betsch (2018, 2019) investigated child decision-making with the Piggy-Bank-Task used in Study 1. We combined all data with the same procedure of data collection. We reanalyzed the data along two questions. First, we were interested in developmental trajectories across childhood that we can now track due to the broadened age range among children. Second, we investigated whether differences between children and older adults suggested by Study 1 are limited to the fourth graders in this study or apply to children of different ages, as well.

4.1 | Group-level analysis

For group comparisons, we added the matching child samples of the previous studies to the data of Study 1 but excluded the young adult samples examined by Lindow and Betsch (2018, 2019). In contrast to Study 1, those adults were convenience samples of university students and might distort a fair comparison with the other age groups. The data set for the group-level analysis included 112 children (52% female; years of age: $M = 9.76$, $SD = 1.03$, range: 8–12) and the 80 adults from Study 1. However, see Figures 2 and 3 for results of the excluded student group ($N = 36$; 81% female; $M = 22.67$, $SD = 2.24$, range: 20–32).

We correlated age and our decision-making measures separately across childhood and adulthood (see Table 4). For visualization purposes, in Figures 2 and 3, we grouped children according to their grade and plotted them in addition to the adult groups. The reanalysis highlights two aspects: Decision-making matures across childhood. Older adults and children have their unique approaches to decision-making. We present these aspects in turn.

Correlational analyses reported in Table 4 showed that choice quality and search quality increased with age in the analyzed child sample of 8- to 12-year-olds. As suggested by the confidence intervals in Figure 2, younger children had difficulty searching the relevant

information and subsequently making good choices. Around fourth to sixth grade, both abilities approached adult-levels. Although it peaks in young adulthood, search adaptivity is already present in the child age groups (see Figure 3) and does not correlate with children's age in the analyzed sample of 8- to 12-year-olds. Search selectivity also does not correlate with age in the child sample. As evident from Figure 2, children performed poorly compared with younger adults. No child age group reached younger adults' performance level, which suggests that the ability to ignore irrelevant information matures later, after sixth grade.

Concerning our second question, the reanalysis supports the notion that children's and older adults' decision-making differs. Search amount was significantly correlated with age in adults but not in children. As illustrated in Figure 2, the frugal search approach suggested for children in Study 1 appropriately described children's search even for the broader age range in the reanalysis. Similar to younger adults, children's search amount was lower compared with older adults. Considering choice quality, the reanalysis highlights an important insight. While older adults generally did well with their information-intense search approach (i.e., no correlation of choice quality and age among adults), children's information-frugal search came with downsides for younger children. In contrast to adults, for children choice quality increased with age and was strongly correlated with search amount. This suggests that, as long as children have difficulty considering information relevance, an information-frugal search approach hampers the ability to make high quality choices.

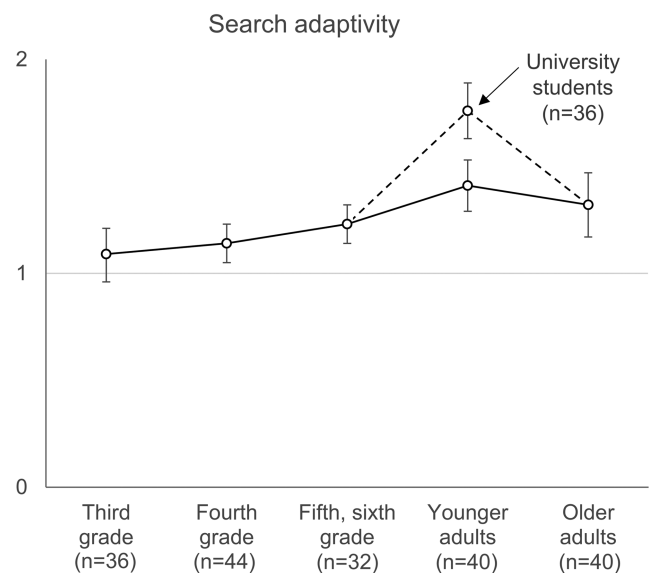


FIGURE 3 Means and 95% CIs of search adaptivity. Scores greater than 1 indicate search adaptivity (i.e., higher search amount in tasks with many relevant information-dimensions). A value equal to one indicates no search adaptivity (i.e., equal search amount for both task structures). The group positioned above the younger adults indicates the performance of the university student samples from Lindow and Betsch (2018, 2019)

TABLE 4 Correlations between age and decision making measures across childhood and adulthood in the reanalysis

	Choice quality	Search amount	Search quality	Search selectivity	Search adaptivity
Children (N = 112)					
Age (range: 8–12 years)	.19*	.16	.23*	0	.17
Choice quality		.48**	.65**	-.12	.35**
Search amount			.91**	.51**	-.02
Search quality				.17	.16
Search selectivity					-.31**
Adults (N = 80) ^a					
Age (range: 20–82 years)	-.12	.27*	-.02	.35**	-.11
Choice quality		.08	.45**	-.32**	.28*
Search amount			.77**	.75**	-.57**
Search quality				.19	-.16
Search selectivity					-.77**

^aWe also performed the correlational analyses with the whole adult sample including the samples of Lindow and Betsch (2018, 2019, N = 116). Results are similar; however, the correlations between age and the decision-making measures are amplified when the university students are included.

* $p < .05$, two-tailed. ** $p < .01$, two-tailed.

4.2 | Individual-level analysis

We complement the preceding analysis with a cluster-analytic approach that explores whether group-level tendencies also account for decision-making on the individual level. The main idea behind a cluster-analytic approach to decision data is to determine whether decision makers “form natural subsets that ‘cluster’ together according to similar behaviour” (Brown et al., 2018, p. 250). Accordingly, we first identified shared approaches to decision-making in our sample by clustering participants according to their performance on *multiple* decision measures. Second, we assessed the prevalence of different approaches in the different age groups. Because data is analyzed individually, the convenience adult samples from Lindow and Betsch (2018, 2019) cannot cause group distortion and were included in the individual-level analysis. Altogether, we used a data set of 228 participants for the cluster analysis.

The cluster analysis suggested a three-cluster solution (see Appendix C for a detailed description of the analysis procedure). To describe the clusters, each variable was scaled to the mean of the whole sample (see *t* statistic in Table 5). Cluster 1 includes 64 participants who showed an information-frugal search amount along with poor scores on choice quality and search adaptivity. In contrast, Cluster 3 includes 91 participants with an information-frugal search amount that went along with above-average choice quality and search adaptivity. Cluster 2 includes 71 participants with an information-intense search amount along with average scores on choice quality and poorer search adaptivity. Our statistical assessment of this cluster solution suggested that we achieved a homogeneous, distinct, and stable solution. However, the importance of relative cluster size—that is, which cluster includes the most participants in the grouping process—should be interpreted with caution, as it was not stable across procedures (see Appendix C).

Figure 4 shows the percentage of participants in each age group assigned to the three decision approaches suggested by the clustering. Evidently, all approaches are represented in all age groups. For third-graders, the predominant approach is information-frugal and results in poor decisions (Cluster 1). In fourth, fifth, and sixth graders, the prevalence of information-frugal and poor decision makers is less frequent (Cluster 1), whereas information-frugal and good decision makers are more frequent (Cluster 3). Approximately one third of participants in each age group shows an information-intense approach (Cluster 2) with the exception of older adults and university students. In older adults, half of participants are allocated to Cluster 2 and the predominant approach is information-intense. In students, the clear majority of participants are information-frugal and good decision makers (Cluster 3), whereas the other two approaches are rare.

Overall, the findings of the cluster analysis converge to group-level findings. The different approaches to decision-making suggested by group-averages can also be detected on the individual level. Although the prevalence of approaches for the different age groups converge to the group-level analysis, our findings indicate that all three approaches coexist throughout development.

5 | GENERAL DISCUSSION

The studies presented here addressed the challenge of investigating the development of ADM by covering a total age range of more than 70 years. In Study 1, we directly compared decision-making in middle childhood to older adulthood while using decision-making in young adulthood as a comparison standard. According to the bounded rationality perspective, ADM is a universal mechanism of decision-making. Although general tendencies should be observable across the lifespan (Gigerenzer, 2003), still, developmental changes are expected due to

TABLE 5 Descriptive statistics for clusters in the reanalysis

	Cluster 1 (N = 64)			Cluster 2 (N = 71)			Cluster 3 (N = 91)			Test of significance ^a
	M	SD	t ^b	M	SD	t ^b	M	SD	t ^b	
Choice quality	61.7	18.7	-0.92	79.6	19.7	-0.06	95.5	8.06	0.70	F(2, 223) = 86.89, p < .01, $\eta^2_{\text{partial}} = .44$
Search amount	39.6	16.6	-1.01	91.5	10.1	1.15	59.6	11.5	-0.18	F(2, 223) = 287.03, p < .01, $\eta^2_{\text{partial}} = .72$
Search adaptivity	1.1	0.2	-0.46	1.0	0.1	-0.74	1.7	0.4	0.90	F(2, 223) = 140.82, p < .01, $\eta^2_{\text{partial}} = .56$

^aANOVA with cluster-allocation as independent variable.

^bt statistic = $(M_{\text{variable in cluster}} - M_{\text{variable in whole sample}}) / (SD_{\text{variable in whole sample}}) / \sqrt{SD_{\text{variable in whole sample}}}$; positive values indicate an overrepresentation of the variable in the cluster, negative values indicate underrepresentation (Backhaus et al., 2018).

age-related changes in cognitive resources that underlie ADM (e.g., Fechner et al., 2019).

Study 1 highlights profound similarities from middle childhood to older adulthood. Fourth graders, younger adults, and older adults all competently searched a subset of information that contained most of the relevant information and subsequently made high quality choices. Moreover, although ADM peaks in young adulthood, all age groups competently adapted search to the requirements of the task structure by searching less information when fewer information-dimensions were relevant. Such pronounced similarities are rather surprising considering previous developmental research (Bereby-Meyer et al., 2004; Betsch et al., 2016; Davidson, 1996). For example, Mata et al. (2011) reported competent, adult-like ADM in sixth graders, whereas the performance of the fourth graders in this study showed clear developmental potential. Although structurally comparable, their decision task was a more complex, probabilistic inference task that involved five information-dimensions whose relevance was conveyed as probabilities and had to be learned via outcome-feedback in successive trials. The lower demands of the decision task applied in the current study might have contributed to an earlier sophistication and created the impression of less developmental differences in our data compared with other developmental studies. To further explore this notion, our reanalysis with previously published Piggy-Bank-Task data broadened the investigated age range of children from third to sixth grade. Children across the investigated age range searched only a subset of the available information. Thus, similar to younger adults, their decision-making was characterized by an information-frugal approach. However, in contrast to younger adults, their frugal search went along with poor choice performance when it did not include the relevant information. Choice and search quality increased in the investigated child sample with age. Thus, our reanalysis of cross-sectional data suggested maturation of decision-making across childhood. The important qualitative change in child decision-making appears to be the ability to focus and systematically compile a good information sample (see also Betsch et al., 2016; Davidson, 1996; Howse et al., 2003; Lindow & Betsch, 2018, 2019; Mata et al., 2011). For example, Lindow and Betsch (2018, Experiment 2) showed that second graders' choice performance even ranged around chance-level when they were forced by instruction to limit their information search—albeit the allowed amount was sufficient to cover all relevant information. In contrast, sixth-graders and adults performed well with limited information search.

In contrast to the younger participants, older adults mainly used a different, more information-intense procedure in Study 1. This finding is surprising for two reasons. First, previous aging research suggests that older adults have information-frugal strategies readily available. To date, strategy-loss in older age has been associated with complex, information-intense strategies (Bruine de Bruin et al., 2016; Mata et al., 2012) and not with more frugal ones (e.g., Bruine de Bruin et al., 2016; Johnson, 1990; Mata et al., 2007; Queen et al., 2012). For example, Mata et al. (2007) report for their—structurally similar—information-board game that older adults clearly use information-frugal procedures. Second, traditional conceptions of cost-accuracy

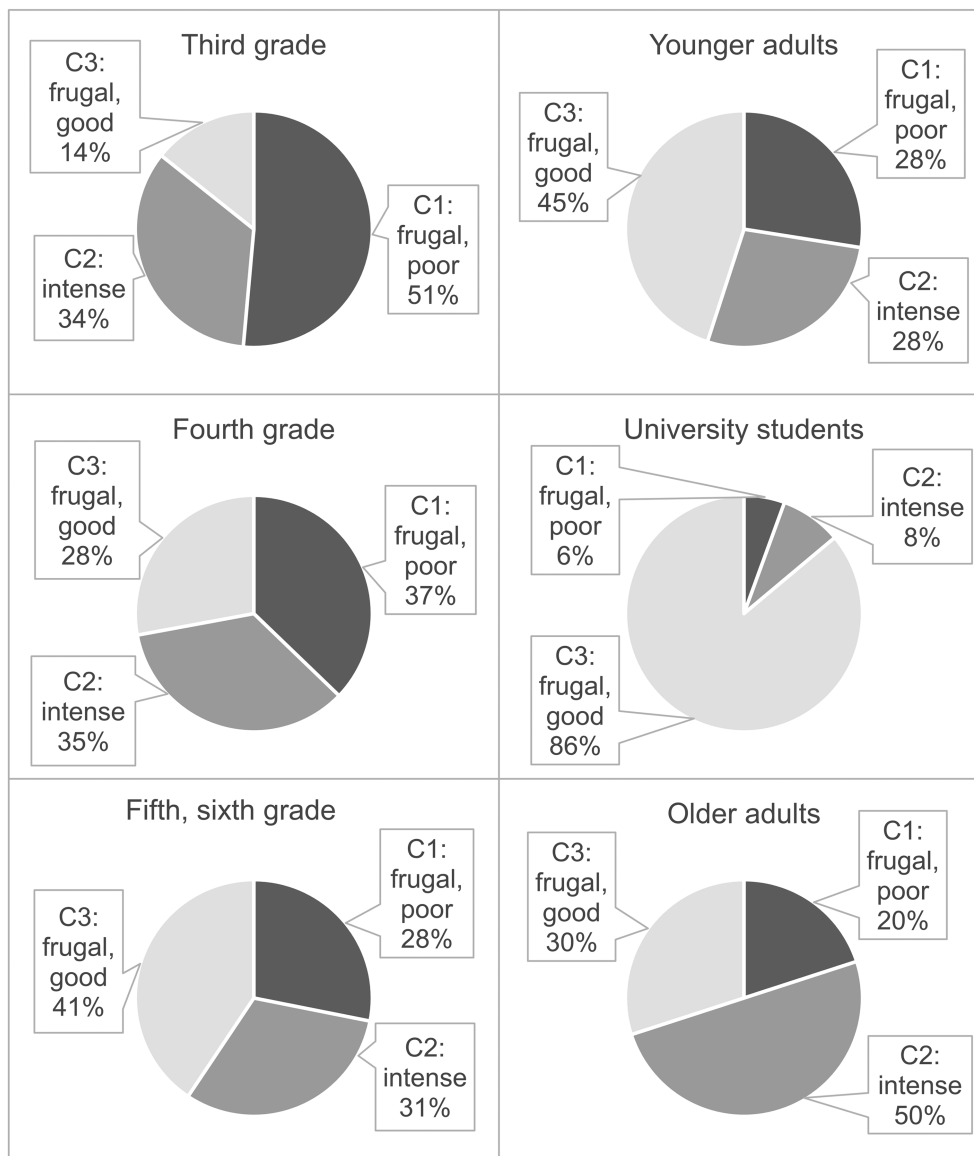


FIGURE 4 Percentage of participants that are assigned to the clusters C1 to C3 according to age group

trade-offs for strategy selection (e.g., Payne et al., 1988) assume an advantage for information-frugal procedures in the presence of cognitive impairments (Hess et al., 2013). In these conceptions, a strategy's cost is defined as cognitive effort, for example, in terms of the number of information processes during strategy execution. Such costs should be amplified when, for example, limitations in working memory or selective attention make strategy execution harder. This would be relevant to children and older adults alike. Our findings imply that this traditional view on strategy selection is not sufficient to capture developmental mechanisms in ADM. More recent evidence on strategy selection raises questions regarding whether sole cost-accuracy considerations are appropriate to describe information search. Alternative psychological mechanisms such as regulating the confidence in a decision (Lee et al., 2014) and the accessibility and saliency of information (Glöckner & Betsch, 2008) also affected the course of information search (overview: Jekel et al., 2018). This emphasizes the need to consider not only content-related information, for example, on the

decision options, but also process-related information. For example, the Parallel Constraint Satisfaction model postulates the operation of two different information networks in decision-making—one network to make a choice between decision options (gathering content-related information) and an additional, separate network that supports this primary network (Glöckner & Betsch, 2008). Thus, there is a second layer of the decision process that guides the handling of content-related information on the basis of process-related information. Importantly, such alternative conceptualizations can go beyond a mere cost-accuracy trade-off. For instance, other types of search-related information and individual differences in their evaluation may be incorporated. This allows distinctive features of older adulthood to be considered. For instance, Hess et al. (2013) have argued that aging is associated with a heightened sensitivity to the allocation of resources as cognitive costs. This mind-set could make cognitive costs appear in a broader manner to aging decision makers. In addition to the “traditional” costs related to strategy execution, costs for strategy

selection might become additionally salient. Investigations of neural processes suggest that selection requires considerable cognitive resources (overview: Mata et al., 2012; but note that Glöckner & Betsch, 2008 propose that strategy selection is an automatic process). Thus, the within-subjects manipulation of task structure could potentially be of particular importance and set our study apart from previous research. Our participants selected the appropriate strategy on a trial-by-trial basis. In contrast, between-subjects designs assess participants' ability to select the appropriate strategy only once and then maintain it as a general rule of the game (e.g., Mata et al., 2007). The findings of Pachur et al. (2009) suggest that this could indeed make a difference in older adulthood. In their study, older adults correctly used the information-frugal recognition heuristic that was appropriate for the majority of tasks. However, older adults (but not younger adults) found it difficult to abandon the heuristic when it was not appropriate. Similarly, in our study, an information-intense procedure yielded high accuracy in both task structures. That is, although information-frugal procedures would have required less effort, it was possible to achieve the same choice quality with information-intense procedures. Thus, older adults might have shown a preference for information-intense procedures because they were appropriate for all types of decisions. This argumentation is in line with previous research suggesting that older adults prefer decision procedures that involve less planning and less attention to the outside world (Gigerenzer, 2003).

The findings of Study 2 yield preliminary support for the assumption that older adults indeed evaluate the decision task in a unique manner. Younger adults generally described all task differences correctly; older adults did so only when the difference was visually salient. In addition, vocabulary scores in Study 1 showed that older adults with a higher crystallized intelligence, potentially indicating a better understanding of task-strategy-fits (Mata et al., 2012), more often used adaptive, information-frugal procedures. Crystallized intelligence might thus compensate for developmental changes in strategy selection and produce inter-individual variability in this age group. The inclusion of cognitive measures, for example, by contrasting the effects of fluid and crystallized intelligence (e.g., Mata et al., 2007; Rosi et al., 2019), appears to be a fruitful approach for future research. This is also highlighted by the results of university students in our reanalysis. These convenience samples of young adults from previous research scored almost perfectly on choice quality. They also mostly outperformed the other participants, including the young adult sample of community volunteers from Study 1 who had a lower educational level. The exploratory results of our cluster analysis further point to meaningful individual differences in each age group that are easily overlooked in group-level analyses. We identified three different approaches to decision-making that matched the age-comparisons on the group-level. However, we also found individual variability within the age groups as such that a mixture of all approaches occurred in all age groups.

Although we covered a wide age range, several interesting age groups were not included in our analyses. In adolescence, for example, differences in risk evaluation might affect decision-making

(Defoe et al., 2015). In middle adulthood, where age-related decline is only beginning, advanced knowledge and experience might benefit decision-making.² Another limitation is that because the specific impact of age-related factors on decision-making depends on task features (Löckenhoff, 2018; Mata et al., 2015; Salthouse, 2004), we cannot expect the identified decision approaches to necessarily generalize to other decision tasks. It is likely that our results are bound to the discussed task features, namely, the within-subjects manipulation of task structure in combination with a rather simple decision task that is within cognitive reach even with impaired cognitive resources. Placing our findings in the context of previous developmental research reveals a need for further studies that apply a lifespan perspective to a variety of decision tasks. In order to understand developmental trajectories, we need longitudinal studies that disentangle potential cohort differences from developmental changes.

6 | CONCLUSION

Overall, the cross-sectional work with the Piggy-Bank-Task suggests that age-related mechanisms affect ADM during childhood and older adulthood differently. Comparable to younger adults, children's search was generally information-frugal. Yet, the ability to execute a systematic, prioritizing search differed between the child samples. This may point to developmental improvements across childhood. The greatest challenge in the development of ADM appears to be the ability to systematically compile a good information subset. As soon as children master this challenge, they can proficiently adapt information-frugal procedures. In contrast to children, older adults relied on a comparably information-intense procedure. Since the decision tasks in the current study allowed participants to use an information-intense procedure, older adults achieved high quality choices while minimizing planning activities. The aging adaptive decision maker appears to perform information-frugal procedures out of necessity (such as in the complex information-boards of Mata et al., 2007). When cognitive functions decline, being frugal may no longer be a valued option but rather a necessity. Age-related differences in strategy selection might explain this pattern. More dynamic conceptions of strategy selection, which acknowledge distinctive age-related and individual features, could help to capture age differences in ADM more adequately (e.g., Glöckner & Betsch, 2008).

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ENDNOTES

¹ As suggested by the age-norms of the PPVT, all participants began with item 85. Following the original test procedure, the test terminated as soon as participants made too many errors. However, the test was carried out to item 192 at maximum.

² We thank an anonymous reviewer for this suggestion.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in OSF at <https://osf.io/rc9aq/>.

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APPENDIX A: PARTICIPANT RECRUITMENT IN STUDY 1

In wave 1 of data collection, a total sample of $N = 94$ across the age groups was achieved. Wave 2 of data collection resulted in a final sam-

ple size of $N = 120$ (see Table A1). Data collection for the age groups was successive: first older adults, then younger adults, lastly children.

TABLE A1 Data collection waves

Age group	Wave	N	Recruitment	Vocabulary scores
Older adults	1	30	Garden club	Yes
	2	10	Sports club	No
Younger adults	1	30	Garden club	Yes
	2	10	Sports club	No
Children	1	34	Science day	Yes
	2	7	Science day	No

APPENDIX B: TASK LIST AND RELEVANT INFORMATION

The same five smiley/frowney constellations (C) were used for tasks with few relevant (FR) and tasks with many relevant (MR) information-dimensions (see Table B1). The following task sequence was used. Task 1: MR/C4; Task 2: FR/C1; Task 3: FR/C5; Task 4: FR/C3; Task 5: MR/C2, Task 6: MR/C3; Task 7: FR/C4; Task 8: MR/C1; Task 9: MR/C5; Task 10: FR/C2.

Relevant information is defined as the information necessary to unambiguously determine the best piggy-bank (see Table B1).

C1	O1	O2	O3	C2	O1	O2	O3	C3	O1	O2	O3
D1	-	-	+	D1	+	-	-	D1	-	+	-
D2	+	-	-	D2	+	+	-	D2	+	-	+
D3	+	-	-	D3	-	+	-	D3	-	-	+
D4	+	+	-	D4	-	-	+	D4	-	-	-
C4	O1	O2	O3	C5	O1	O2	O3	Practice	O1	O2	O3
D1	-	+	-	D1	-	-	-	4 coins	+	-	-
D2	-	-	-	D2	+	+	+	3 coins	+	-	+
D3	+	+	-	D3	+	-	-	2 coins	-	+	-
D4	-	-	+	D4	-	+	-	1 coin	+	+	-

TABLE B1 Smiley/frowney constellations and relevant information in the decision tasks

Note: C1 to C5 denote the different smiley/frowney constellations. D1 to D4 denote the information-dimensions (i.e., the money-bags), where 1 indicates the most relevant and 4 the least relevant dimension. O1 to O3 denote the options (i.e., the piggy-banks). Plus and minus signs correspond to the smileys and frowneys and display whether the money-bag is contained. Shading shows the relevant information. In tasks with few relevant information-dimensions, only the dark shaded information is relevant. In tasks with many relevant information-dimensions, the light shaded information is additionally relevant.

APPENDIX C: CLUSTER ANALYSIS IN THE REANALYSIS

C.1 | Preparation of the data set

We only included the measures choice quality, search amount, and search adaptivity in the cluster analysis. We followed common recommendations and excluded strongly correlated variables (i.e., search selectivity and search quality), as they would overweight certain behavioral aspects in the analysis (Backhaus et al., 2018; we defined $r > .5$ as a strong correlation according to Cohen's conventions). Second, we excluded outliers, that is, participants who have a completely different combination of characteristics, as they may distort the detection of relationships among the other participants (Backhaus et al., 2018). To detect outliers, we performed hierarchical cluster analysis using the nearest-neighbor algorithm with the Euclidean distance and z-standardization of the variables. We excluded the two participants who were clustered in the last clustering step from further analysis ($N = 226$).

C.2 | Data analysis procedure

We performed a hierarchical cluster analysis since we sought to derive the clusters from the data instead of optimizing a predefined solution. We used the agglomerative Ward's algorithm because of its suitability to detect possibly homogeneous clusters. It is associated with determining the “right” groups with regard to both the number of clusters and the grouping of subjects (see Backhaus et al., 2018, for further discussion). We chose a distance proximity measure, the Euclidean distance, because in our case the analysis of the absolute level is more meaningful than the profile trend of the variables. We did not square the Euclidean distance to avoid overweighting larger differences. A z-standardization of the variables was performed to control for unequal scaling of search adaptivity.

C.3 | Cluster solution

To determine the number of clusters in our data set, we plotted the increase in total within-cluster variance for each cluster solution in Figure C1. The applied agglomerative Ward's algorithm begins with 226 clusters (i.e., each participant represents one cluster) and then groups clusters with the aim to minimize the total within-cluster variance at each clustering step. Thus, one should accept the cluster solution before the first larger increase in total within-cluster variance (i.e., elbow-criterion, Backhaus et al., 2018). In our case, a three-cluster solution is indicated, as the subsequent two-cluster solution coincides with a comparably large increase (see Figure C1).

To assess the three-cluster solution, we first considered the achieved homogeneity within the clusters by consulting the F statistics (i.e., the ratio of a variable's variance in a cluster to its variance in the whole sample). The F statistics are smaller than one for all three variables (i.e., choice quality, search amount, and search adaptivity) in all three clusters. Thus, we can assume that the clusters are fully homogeneous. Second, we assessed the distinction of the cluster solution with univariate analyses of variance for choice quality, search amount, and search adaptivity as the dependent variable and the cluster-allocation as the independent variable. Results confirm that the clusters differ significantly on all three variables (see test of significance in Table 5). Following common recommendations, we repeated the cluster analysis with other constellations of settings regarding the number of variables, number of participants (i.e., no exclusion of outliers), and proximity measure (e.g., Backhaus et al., 2018). The three-cluster solution as well as the overall interpretation of the clusters is stable across these variations. However, relative cluster size should be interpreted with caution. The applied Ward's algorithm aims at finding clusters of relatively equal size. Because the means of the variables within the clusters diverge slightly for the different analysis procedures, the cluster that receives the most participants in the grouping process varies.

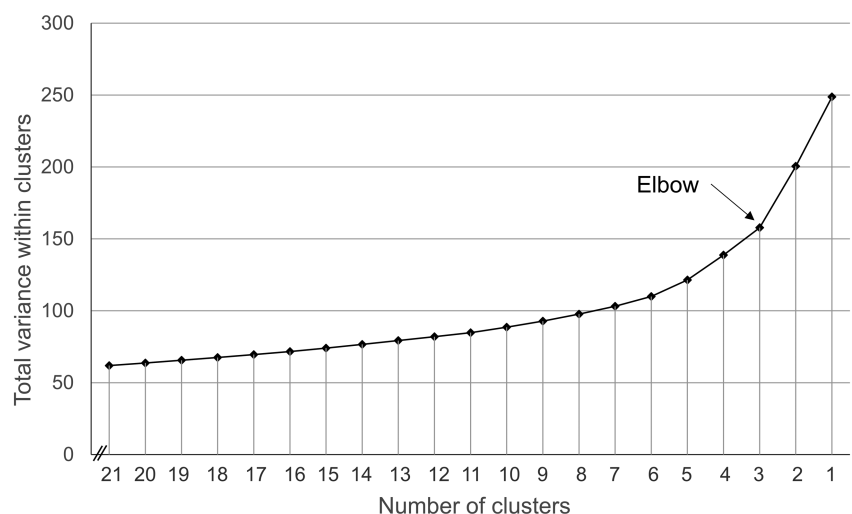


FIGURE C1 Plot of within-cluster variance for the clustering steps. “Elbow” indicates the suggested cluster solution, that is, the clustering step prior to a relatively large increase in variance. Plotting begins with 21 clusters