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Appraisal of Children's Facial Expressions while Performing Mathematics Problems

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Abstract

We show that children display facial expressions when solving mathematical problems, and that adults can infer from these facial expressions whether a child finds the problem easy or difficult. More specifically, we show an age difference in displaying facial expressions while solving math problems. Eleven-year old children display more facial expressions when solving a difficult problem than 8-year olds, and are also rated to be faced with more difficult problems by adult observers. The opposite is true for easy problems. Results of our studies can be used for the development of automatic detection of affective state in educational computer environments. These environments can then adapt the difficulty level of tasks to the individual child.

Keywords: facial expressions; learning; appraisal; mathematics; primary education.

Introduction

When children are performing school tasks, their faces often show how they feel. The face has been called the primary source of information for someone's internal state (Knapp & Hall, 2006), and in interaction, facial expressions support the information a speaker wants to convey (e.g., Ekman, 1979; Barkhuysen, Krahmer & Swerts, 2005).

The detection of children's affective state when performing school tasks is very important for several reasons. First, learning occurs when children incorporate new knowledge into their existing knowledge. Ideally, tasks are in children's 'zone of proximal development' (Vygotsky, 1978). If a task is too easy for children they will not learn. However, if the task is too difficult they will also not learn, because the new information does not relate to existing knowledge. Children's faces may show us whether the task is too easy or too difficult for them, and enable us to adapt the level of task-difficulty accordingly. Second, children may not yet be able to express themselves verbally very well, which makes their non-verbal reactions a valuable source of information. It seems easier for children to express themselves non-verbally, also in school tasks. For example, Alibali (1999) found that when children generate new problem-solving strategies, they often first show gestures expressing these strategies before being able to verbalize them. Third, children's facial expressions may reveal their level of meta-cognitive awareness. Meta-cognition is important for regulating one's own learning.

Smith & Clark (1993) showed that people signal uncertainty in factual question-answering situations by a variety of verbal prosodic cues, and Swerts & Krahmer (2005) extended this finding to the visual domain.

Expert teachers seem to be able to infer children's affective state from their verbal and non-verbal expressions, and modify their pedagogical tactics accordingly (Meyer & Turner, 2002). However, until now we do not know exactly on what grounds teachers evaluate how children are doing while performing school tasks. Previous research has shown that affective states such as frustration, boredom, interest and confusion can occur in learning (Craig et al, 2004), but has not related these states to specific expressions.

In this paper, we report on two studies done to investigate whether the perceived level of difficulty of mathematics problems is shown in children's facial expressions, and whether adults can evaluate these expressions correctly.

1. Do children show facial expressions when solving mathematics problems?
2. Can adults interpret these facial expressions to infer whether the children are dealing with an easy or difficult mathematics problem?

Besides these two general questions related to affective states in facial expressions while performing math tasks, we also include a specific question related to age. Generally, children are more expressive than adults. Thompson (1994) argues that younger children are more expressive than older children are. As said before, children may be very expressive in their faces because of their limited verbal abilities. Thus, when children grow older they might not need to express themselves non-verbally as much as before because of their improved verbal skills. On the other hand, they might also have adapted their facial expressions to support the verbal information they want to convey. In addition, children may learn how to control their facial expressions for social reasons while growing up (Krahmer & Swerts, 2005). Therefore, our third question is:

3. Are older children less expressive in their face while solving math problems than younger children?

Not only novice teachers could greatly benefit from the knowledge of how to detect children's inner state, but knowledge on facial expressions in learning could also be used to improve educational software. Computers have become an intrinsic part of education. Many software tools

have been developed to assess children's knowledge and skills. One of the advantages of using a computer to provide children with tasks is that they can be adaptable to the individual child. Some programs have been developed that adapt the difficulty level when children give many wrong answers. However, whether the answer is right or wrong is not the only thing important for learning. For example, a learner can be engaged in a task and enjoy trying things even when making mistakes, because the task is still in his or her zone of proximal development. On the other hand, it may be good to adjust the difficulty level when the learner is showing signs of increased frustration when making errors (Kapoor, Mota & Picard, 2001). Researchers are slowly starting to investigate the detection of affective states in learning in order to incorporate these aspects into educational software (Craig et al., 2007; Kapoor, Mota, Picard, 2001). Our study aims to contribute to this line of research, paving the way for automatic detection of affective states in learning by collecting suitable training materials.

Data Collection

In order to collect facial expression data during learning tasks, we elicited responses from children to easy and difficult math problems. Math problems were chosen because they have straightforward answers and there are clear guidelines on what level of math problem a child at a certain age should be able to solve.

Design

We employed a mixed 2x2 design with grade (second grade, fifth grade) as between-subjects variable, and level of difficulty (easy, difficult) as within-subjects variable. The order of the math problems was randomly varied to prevent order-effects.

Participants

Fifty-eight children from a primary school in the Netherlands participated in this study; twenty-nine from second grade (group 4 in the Dutch school system) and twenty-nine from fifth grade (group 7). The 14 boys and 15 girls in second grade had a mean age of 7 years and six months ($SD = 0.51$), and the 14 boys and 15 girls in fifth grade had a mean age of 10 years and nine months ($SD = 0.48$). Parents were informed about the experiment beforehand and returned a consent form for their child's participation and usage of recorded material for research purposes.

Materials

A PowerPoint presentation (Figure 1) was developed with mathematical problems at an easy and a difficult level. The PowerPoint resembled Dr. Kawashima's Brain Training, an educational game developed for the Nintendo DS. Many children in the Netherlands are familiar with this game and play it regularly themselves. In this game, as in ours, people have to solve math problems as fast as they can. Children's

reactions to the math problems were recorded with a video-camera placed behind the laptop on which the math game ran. The problems were taken from an official test children take regularly in the Dutch school system, the Tempo Test Rekenen (Tempo Test Mathematics, De Vos, 1994). The difficulty level was based on norms of what the children's level should be. Thus, half of the problems for each grade were taken from a level far below the children's current ability level, and half of the problems were taken from a level high above their current ability level.

Procedure

The children were asked to play a math game to help us get new input for Dr. Kawashima's Brain Training. They carried out this task one by one, in a separate room in the school. The experimenter first talked to the children to make them feel at ease, and told them that the task was a game and did not involve getting a grade. The PowerPoint started with explanation slides from Dr Kawashima and then 12 easy and 12 difficult math problems. Children were asked to answer the problems facing the camera. At the end of the slides, Dr Kawashima calculated the children's intellectual age, and systematically gave them a higher age than their real age. This was done to encourage the children and prevent frustration from the difficult problems. At the end of the experiment, children were asked to indicate the general level of difficulty and fun they experienced in playing the game. This was done with a five-point scale consisting of facial representations, with the items changing from a sad face (mouth corners pulled down) to a smiling one (mouth corners pulled up). These scales are often used with children (e.g., Lockl & Schneider, 2002; Read, MacFarlane & Casey, 2002). All children received a small treat to thank them for their participation.
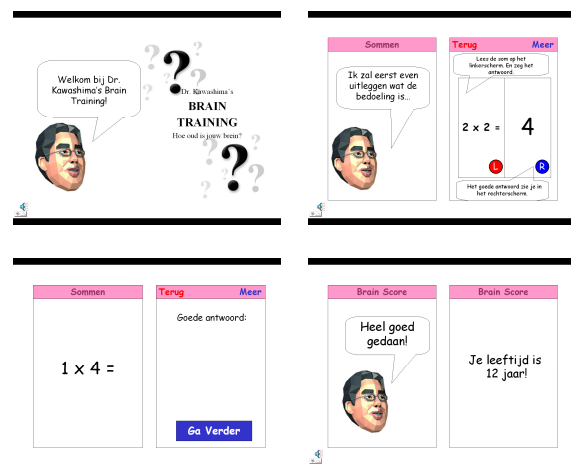

Figure 1. PowerPoint slides showing welcome, explanation, a simple math problem and age calculation

Figure 2. Facial expressions in answering math problems
(clockwise from top left: funny face, laughing, averted gaze, frowning)

Results

Figure 2 shows representative stills of children's reaction after receiving an easy or a difficult math problem. Overall, the game worked quite well. All children liked the task, $M = 4.17$ ($SD = .60$) on a five-point scale ranging from 'I did not like the game at all' to 'I liked the game very much'. The majority of children (34 out of 58) rated the task 'not easy/ not difficult', $M = 2.88$, ($SD = .68$) on a scale ranging from very difficult to very easy, which suggests that the math problems taken from the Tempo Test Mathematics were indeed both easy and difficult for their level. There was no significant age difference in the amount of fun or level of difficulty children experienced.

Furthermore, the data gathered seem rich in facial expressions. Informal observations reveal differences in facial expressions between the easy and difficult problems and between age groups, which we attempt to validate in a perception experiment.

Perception of Task Difficulty

In the perception experiment, adults rated the children's facial expressions while responding to a math problem to investigate whether they could accurately detect perceived level of task-difficulty.

Design

The experiment was a 2x2 within subjects design, with grade (group 4 and 7) and level of difficulty (easy, difficult) as variables. All participants saw all variables on film. The order of the fragments was randomly varied in two versions of the film to compensate for potential learning effects.

Participants

31 adults participated in this experiment (15 male, 16 female). Their mean age was 37 and a half (SD = 14.3) and their level of education varied.

Materials

A film consisting of 114 fragments of children from the data collection was given to all participants. These fragments included one randomly chosen easy ($1 \times 4 = 4$) and one randomly chosen difficult math problem ($87 - 12 = 75$ for group 4; $193 + 159 = 352$ for group 7) from every child. One child was taken out of this experiment because he did not give an answer to the difficult problem. The fragments were cut from the moment the children had seen the problem until they gave an answer, regardless of whether the answer was right or wrong. The participants rated all 114 fragments by completing the sentence "I think the child found the problem..." choosing from very easy to very difficult on a seven point scale. Sound was excluded from the film.

Procedure

Participants individually saw the film with 114 fragments on a laptop. They were told that the children on the film were solving an easy or a difficult math problem, and that they, as viewers, had to guess how much difficulty the children experienced with the math problem. Participants first saw a trial version of eight fragments, during which they could ask for clarifications. Then they saw the actual film with 114 fragments. Before each fragment, a number was shown together with a sound, to indicate a new fragment was starting. Immediately after each fragment, participants were asked to fill the question on the child's experience of difficulty-level on a seven-point scale. They had three seconds to score the fragment. After 57 fragments, participants were allowed a short break.

Results

The scores for the two versions of the film we made to prevent order effects did not differ significantly, so we combined the results of both versions.

We found a significant difference between easy and difficult problems on the perceived difficulty level. This means that participants rated children's reactions to difficult problems indeed as indicating a high difficulty ($M = 3.31$, $SD = 0.15$), and their reactions to easy problems as indicating low difficulty ($M = 6.44$, $SD = 0.07$), $F(1, 30) = 671.12$, $p < .001$, $\eta^2 = .96$.

Results show a significant difference between grades on perception of difficulty level. According to the participants, group 7 children showed higher levels of difficulty in their expressions ($M = 4.79$, $SD = 0.07$) than group 4 children did ($M = 4.96$, $SD = 0.08$), $F(1, 30) = 17.89$, $p < .001$, $\eta^2 = .37$.

There was also a significant interaction between grade level and difficulty level, $F(1, 30) = 319.80$, $p < .001$, $\eta^2 = .91$, indicating that the perceived differences between easy and difficult problems in facial expressions is higher in group 7 than in group 4 (see Figure 3).
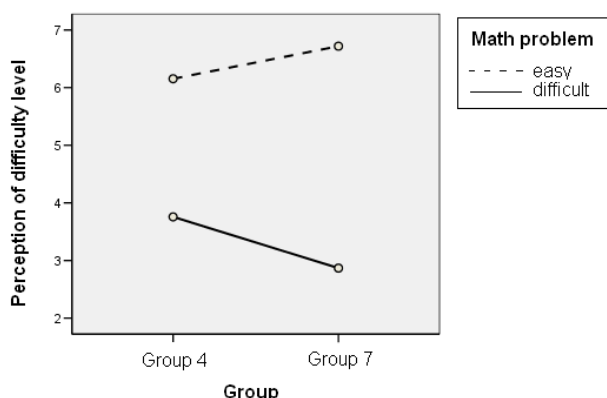

Figure 3. Perception of difficulty level for easy and difficult math problems inferred from facial expressions in two group levels. High scores indicate the problems were easy, low scores indicate the problems were hard.

Analysis of Facial Expressions

The results of the perception experiment suggest that adults can perceive whether children find a given math problem easy or difficult by watching their face. The results also suggest that facial expressions vary with age. To further investigate which facial expressions children show and whether these are related to the results of the perception experiment, we analyzed the facial expressions of the children in all 114 fragments.

The 114 fragments of children's reactions to math problems were coded on five facial expressions: (1) smiling, (2) gaze, (3) frowning, (4) 'funny face' (a marked facial expression, which diverts from a neutral expression, Swerts & Krahmer, 2005), and (5) visual delay in answering. Verbal clues were not included in the analysis. The features are loosely based on some of the Action Units (AUs) described by Ekman & Friesen (1978) to distinguish facial expressions and the facial muscles involved. Of the visual features under consideration here, smiling is related to AUs 12 and 13 and gaze to AUs 61-64. Frowning is related to AUs 1 and 2. Funny faces typically consist of a combination of AUs such as lip corner depression (AU 15), lip stretching (AU 20) or lip pressing (AU 24), combined with eye widening (AU 5) and possibly brow movement as well. Representative examples of these facial expressions are displayed in Figure 2.

For every fragment, the five expressions are scored as present ($= 1$) or not present ($= 0$). Each reaction to a math problem could thus score a minimum of 0 facial expressions and a maximum of 5 facial expressions.

Results

Table 1 shows the frequencies (114 fragments) of shown facial expressions, split by difficulty level of the math problem and group level.

On average, children show significantly fewer expressions when they are faced with an easy problem ($M = .32$; $SD = .51$) than when faced with a difficult problem ($M = 1.91$, $SD = 1.01$), $t(112) = -12.41$, $p < .001$. Smiling occurs both when facing easy and difficult problems, $t(112) = 1.25$, $p = .21$, while all other facial expressions occur significantly more often when a problem is difficult than when it is easy ($p < .001$).

There is no significant difference in amount of expressions shown between group 4 and group 7, $t(112) = -.51$, $p = .61$.

A significant strong negative relation ($r = -.81$, $p < .001$) was found between the perceived level of difficulty and the facial expressions. This means that participants think that children are solving simpler problems when they show fewer facial expressions.

Table 1. Frequencies of shown facial expressions and delay in easy and difficult math problems in two groups

| | | Easy | | Difficult | |
		Group 4	Group 7	Group 4	Group 7
Smiling	*yes*	5	7	2	5
	no	23	22	26	24
Gaze	*yes*	0	0	11	9
	no	28	29	17	20
Frowning	*yes*	0	0	3	10
	no	28	29	25	19
Funny face	*yes*	2	0	8	11
	no	26	29	20	18
Visual delay	*yes*	4	0	22	28
	no	24	29	6	1

There is a significant interaction between grade level and difficulty level, $F(1, 110) = 5.83$, $p < .05$, $\eta^2 = .05$, indicating that the differences in the amount of facial expressions between easy and difficult math problems is higher in group 7 then in group 4 (see Figure 4).
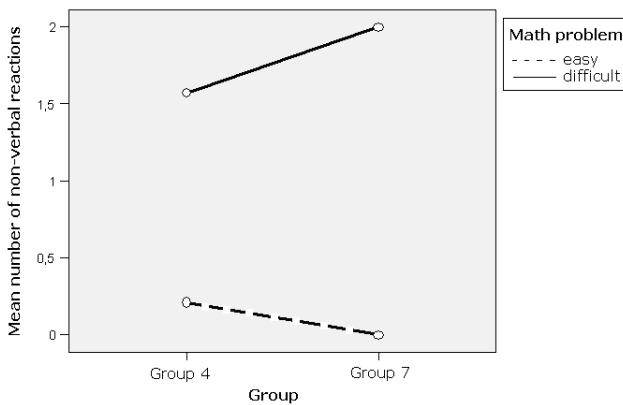

Figure 4. Mean number of facial expressions while answering math problems for two group levels.

General Discussion

In this paper we have shown that children display facial expressions when solving mathematical problems, and that adults can interpret these facial expressions. There was a strong relation between adults' ratings of perceived difficulty inferred from the facial expressions and the actual difficulty level of mathematical problems. In other words, facial expressions showed that children indeed found easy problems easy, and difficult problems difficult. Note that adults were just told they had to judge problem difficulty, and that the only cues they could rely on were the facial expressions; adults were not told about an expected correspondence between facial expressions and difficulty-level.

In easy problems, the facial expression most shown was smiling. When children answered difficult problems, they showed a variety of facial expressions, such as gaze, frowning, a funny face, and visual delay. Although we did not ask participants on which (combination of) factors they based their decision of difficulty level, we found a relation between their ratings and our analysis of the facial expressions. This suggests that children's perceived difficulty of the math problems could be inferred from the facial expressions we analyzed. It also suggests that the more facial cues were shown, the more difficult a mathematical problem is perceived to be. Further research could investigate what factors contributed most to the accuracy of responses.

Overall, children in group 4 showed as many facial expressions as children in group 7. However, the children in group 7 were rated to show higher difficulty in difficult problems. This is supported by the fact that children in group 7 show more facial expressions on average when facing difficult problems than children in group 4. One possible explanation for this finding is that the difficult problems group 7 had to solve were more difficult than the problems group 4 had to solve. However, this is only true in an absolute sense. Problems that are difficult for group 4 are relatively easy for group 7. We chose difficult math problems according to the norms applicable to the group children are in. A more plausible explanation is that children in group 7 are more expressive when facing a difficult problem. This finding seems to be incompatible with expectations based on the theory that younger children are more expressive than older ones (Thompson, 1994), but consistent with the findings of Shadid, Krahmer & Swerts (2008) that 12 year old Pakistani and Dutch children were more expressive playing a game than 8 year olds. However, the interaction effect we found between grade level and expressions is difficult to interpret in this light. Group 7 children are more expressive when facing difficult math problems, but less expressive when facing easy math problems compared to group 4 children. It is possible that the easy problems were so easy for group 7 children that they could hardly take them seriously and therefore it did not really affect them. Another possibility is that there is a difference in displaying positive and negative affect in children. Further research could shed light on this issue.

Our results show that difficulty level of mathematics problems can be inferred from facial expressions, which

makes it possible to use facial expressions to adapt educational software to individual ability levels. To extend our findings to educational software, we will investigate whether a computer can automatically detect perceived difficulty based on the five facial expressions we analyzed. Automatic detection of AUs as described by Ekman & Friesen (1978) may be very helpful in this respect. However, we conjecture that low-level features such as the overall amount of facial movement in a given interval may be indicative of difficulty as well. Of course, children's affective state is not only based on the difficulty level of the problem they face, but can change depending on goals and expectations for example (Conati, 2002). We will therefore extend our research to include factors such as motivation and boredom for future computer environments.

Acknowledgments

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