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Action at Its place: Contextual Settings Enhance Action Recognition in 4- to 8-Year-Old Children

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Actions are recognized faster and with higher accuracy when they take place in their typical environments. It is unclear, however, when contextual cues from the environment become effectively exploited during childhood and whether contextual integration interacts with other factors such as children's perceptual or motor experience with an action. In the present experiment, we asked 4- to 8-year-olds (n = 159) to recognize pantomime actions that took place in compatible, incompatible, or neutral contextual settings. In each age cohort, children recognized more actions taking place in compatible compared to incompatible and neutral contexts. This result demonstrates robust facilitation effects of context on action recognition independent of age. Additionally, we found an interaction of context effects with action familiarity: Context effects were strongest when the children were less familiar with the actions, suggesting that contextual settings are particularly beneficial for action recognition when experience with an action is sparse.

Keywords: action observation, context, scene, semantic integration, experience

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One usually perceives actions of others in specific contextual settings. This co-occurrence of context and action influences the perception of actions: Actions in compatible contexts are recognized faster and with higher accuracy than actions in incompatible contexts (Wurm & Schubotz, 2012, 2016). This context effect is suggested to result from exploitation of functional associations between context and action information that develop during prior experience. The associative strength between context and action is likely to be a frequency-based function of co-occurrence. If so, the associations between certain contexts and actions are selectively strengthened because their combination is observed more frequently than others are. The formation of context–action associations is suggested to follow the rules of statistical Hebbian learning in a way that is similar to what has been observed for other kinds of visual stimuli (Munakata & Pfaffly, 2004).

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The exploitation of context–action associations should be beneficial for action recognition: Preactivation of expectable actions by contextual information reduces the search space for input–memory matching by biasing those actions that are most likely to take place in a given context (Wurm & Schubotz, 2012). Notably, places and scenes are typically recognized much faster than are unfolding actions (Oliva, 2005). Thereby, context–action associations have the potential to provide shortcuts to action recognition. In addition, places and scenes are informative about more distal goals of context-specific actions (e.g., kitchen—cooking), which facilitates the inference of superordinate goals and intentions (Jacob & Jeannerod, 2005; Kilner, Friston, & Frith, 2007; Wurm & Schubotz, 2012, 2016) and the prediction of possible follow-up action steps (Kilner, 2011; Wurm & Schubotz, 2012).

The influence of context on action perception is also reflected by changes in neural activity in brain regions involved in action observation. In general, behavioral facilitation is reflected by attenuation of metabolic costs and thus by attenuation of the signal measured in functional magnetic resonance imaging (fMRI). Accordingly, activity in the lateral occipitotemporal cortex, a region involved in the perception and semantic processing of actions (Noppeney, 2008; Wurm, Ariani, Greenlee, & Lingnau, 2016; Wurm & Lingnau, 2015), attenuates when observed actions take place in compatible compared to incompatible or neutral settings (Wurm & Schubotz, 2012). Additionally, neural activity in the ventrolateral prefrontal cortex, a region involved in semantic retrieval, selection, and integration (Badre & Wagner, 2007), increases when observed actions take place in incompatible compared to compatible or neutral settings, possibly due to increased demands in reconciling the observed action with overarching goals associated with the incompatible context (Wurm & Schubotz, 2012).

In summary, there is substantial evidence for context–action associations in learning and memory and the effective exploitation of such associations during action recognition. However, it is unclear when context–action associations are established and become effective in child development and whether the effectiveness of context–action associations depends on certain developmental factors. Such knowledge would help to shape theories about the development of action understanding.

Regarding the principles of Hebbian learning, context–action associations should be established as soon as children are exposed to actions in their typical contexts. To date, there are no systematic investigations of statistical learning on the development of context–action associations. However, statistical learning was demonstrated for speech and action segmentation in 8-month-olds (Roseberry, Richie, Hirsh-Pasek, Golinkoff, & Shipley, 2011; Saffran, Aslin, & Newport, 1996), suggesting that infants at this young age extract and use statistical properties of perceptual input. It is interesting that habituation experiments revealed that it is around the same age when children begin to attribute goal-directed actions to agents, which can serve as an approximate measure of action goal inference (Csibra, 2008; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Sodian, Schoeppner, & Metz, 2004).

It is unclear, however, at which point in child development context–actions associations are effectively exploited during action observation. One possibility is that context–action associations develop and become effective as soon as children observe actions in their typical contexts and that these associations remain stable during childhood (under the assumption that the frequency of observing actions in their typical context is constant during childhood). On the other hand, the strength and effectiveness of context–action associations might change during childhood. A hypothesis can be derived from pretend play. Pretend play typically refers to the "as if" use of objects, for example, to use a remote control as if it were a telephone (Fein, 1981; Lillard et al., 2013). One implication of pretend play that could be critical for the strength of context–action associations is that pretend play actions usually do not (have to) take place in the action's typical contextual setting—for example, pretending that a cooking action must not necessarily take place in kitchens. Hence, it is possible that the strengthening of context–action associations is reflected in children's decreasing engagement in pretend play. Pretend play activities emerge during the second year of life, increase until the age of 5 to 6, and decline afterward (Fein, 1981; but see Smith & Lillard, 2012). Thus, if the strength of context–action associations correlates with the frequency of pretend play, then one should observe increased context–action compatibility effects after the age of 6.

In this study, we investigated children ranging from 4 to 8 years of age to test whether context effects on action recognition are established and change during childhood. We asked children to guess kitchen and playing actions from object-free pantomimes taking place in kitchens, children's rooms, or against a neutral (white and empty) background. Actions and contexts were crossed so that actions were compatible, incompatible, or neutral regarding the context (factor contextual compatibility; see Figure 1A). Pan-

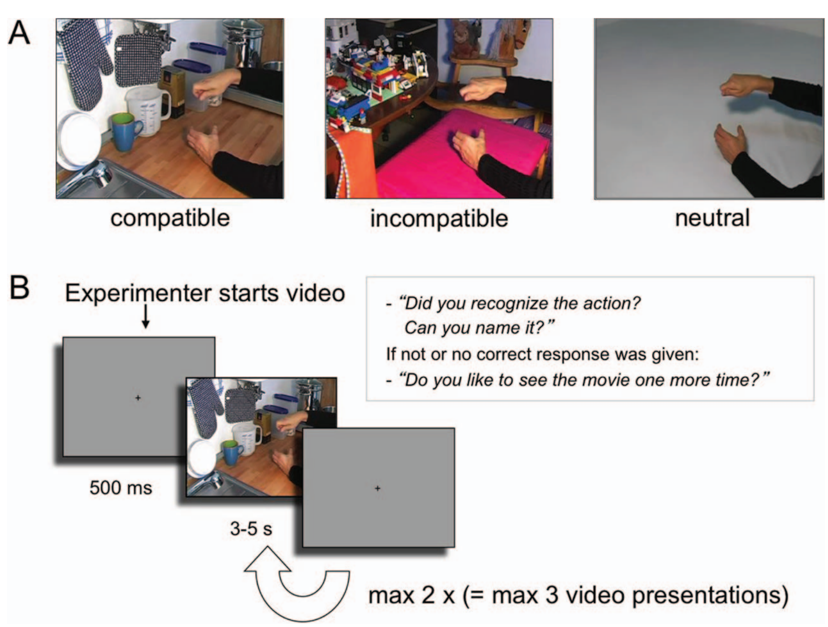

Figure 1. Experimental conditions (Panel A) and trial design (Panel B). Stimuli consisted of movies of 18 pantomimed actions filmed in compatible, incompatible, and neutral contextual settings. Stimuli were balanced across children within each age group so that each child observed each action only once during the experiment (18 trials, six trials per condition). Children were asked to name the pantomimed action. In case no response or a false response was given, the children were allowed to watch the movie again (a maximum [max] of three times). See the online article for the color version of this figure.

tomimes were employed to deplete object information in the stimuli. We thereby selectively measured effects of context–action associations in the absence of putative interacting context–object associations (Bar, 2004; Wurm, Cramon, & Schubotz, 2012). Children within the selected range of age are capable of identifying action from pantomime (Bigham & Bourchier-Sutton, 2007). Note, however, that the ability to recognize actions from pantomime is still developing within this age range, and for 4-years-olds action recognition performance is relatively low, that is, about 30% (Bigham & Bourchier-Sutton, 2007). We therefore expected recognition rates to increase with age. Critically, we were interested in whether recognition performance is modulated by contextual compatibility, in particular in interaction with age. Higher accuracy for recognition of pantomimed actions in compatible compared to incompatible and neutral settings was taken to suggest facilitation of recognition by compatible settings, whereas lower accuracy for recognition of pantomime actions in incompatible compared to compatible and neutral settings was taken to suggest interference of recognition by incompatible settings.

For additional exploratory analyses, we tested whether putative context effects interact with action familiarity, that is, a child's perceptual and motor familiarity with an action by observation and execution, respectively. The influence of action familiarity on action recognition is well documented (for a review see Hunnius & Bekkering, 2014). Action familiarity might interact with contextual compatibility in two alternative ways: First, under the assumption that actions are usually experienced in their typical environments, one should expect that with increasing action familiarity the strength of context–action associations should also increase. In this case, measured context effects should be stronger for familiar compared to unfamiliar actions. Second, and to the contrary, context–action associations could already form with little familiarity. Indeed, statistical learning results in effective associations already after a relatively short time, that is, in tens of minutes (Smithson, 1997; Tobia, Iacovella, Davis, & Hasson, 2012; Turk-Browne & Scholl, 2009). One may therefore argue that even little action experience results in the formation of exploitable context–action associations. Critically, context–action associations should be particularly helpful when actions are unfamiliar and thus hard to recognize. In that case, context effects should be stronger for unfamiliar compared to familiar actions.

Method

Participants

One hundred seventy-four 4- to 8-year-old children participated in the experiment. Nine children had to be excluded due to self-chosen termination ($n = 6$), insufficient language skills ($n = 2$), or technical errors ($n = 1$). Six additional children were excluded after an outlier analysis performed separately in each single age group. The remaining 159 children of the final sample were assigned to five age groups: twelve 4-year-olds (nine female; $M = 4$ years, 2 months; range = 3,8–4,6), thirty-six 5-year-olds (22 female; $M = 5,1$; range = 4,7–5,6), twenty-nine 6-year-olds (17 female; $M = 6,0$; range = 5,7–6,6), forty-five 7-year-olds (21 female; $M = 7,0$; range = 6,7–8,4), and thirty-seven 8-year-olds (18 female; $M = 7,11$; range = 7,7–8,4). For six participants (three 4-year-olds, three 5-year-olds), low performance resulted in absence of data points for one or more levels of the factor contextual compatibility. These participants were excluded from the analyses of context effects.

The choice of sample size was based on the effect size (partial $\eta^2 = .1$) and observed power ($1 - \beta = .76$) of a comparable study in adults (Wurm & Schubotz, 2016). A sample size estimation using the software package G*Power (Faul, Erdfelder, Lang, & Buchner, 2007) indicated that a minimum sample size of $N = 60$ (i.e., approximately 12 children for each age group) would be needed to detect a moderate effect ($d = .33$; Cohen, 1988) for a within–between interaction (repeated-measures analysis of variance [ANOVA] with three levels and five age groups) with a power of .8 at an alpha level of .05 ($N = 85$ for a power of .95). Note that this analysis provided only an approximate estimation, because we used different statistical methods (linear mixed effect models; see the Analysis section), as did Wurm and Schubotz (2016).

Children were recruited from day cares and primary schools in the city of Cologne, Germany. They were primarily European, had mixed socioeconomic backgrounds, and were native German speakers. Parents provided written informed consent. The experiment was approved by the local ethics committee of the Medical Faculty of the University of Cologne. After the experiment, all children received a little toy present.

Stimuli

Stimuli consisted of video clips with a duration of 3–5 s ($M = 4.4$ s; range = 3.2–5.3 s; 25 frames per second; 900 × 720 pixels) that showed pantomimes of nine kitchen actions and nine playing actions (see the Appendix for details) taking place in kitchens, playrooms, or against a white background that served as a neutral context (see Figure 1A). In all contexts, the actions were filmed from an allocentric perspective (about 60° left of the actress; see Figure 1A) to provide a convenient view of both the action and the contextual setting. Care was taken that each action was performed in an identical manner in each context. To enhance the variance of the contexts, each action was performed in two different kitchens and playing rooms. We induced additional variance by placing different context-specific objects in the scene and changing their positions within the scene. In total, 108 videos were used (18 actions × 3 contextual compatibility conditions × 2 versions). In addition, we filmed each of the 18 actions in their natural way, that is, with the respective objects. These stimuli were used in a control study after the main experiment to test whether the children were familiar with the actions and able to name them. Finally, we filmed three additional pantomime actions (washing hands, painting, kneading dough). These videos were used as training trials.

Experimental Design

For each participant, each of the 18 actions was shown only once during the experiment. Thus, the stimuli were balanced across participants, so that each condition and each context was shown equally often per participant (each condition six times, each context six times). Additionally, the trial order was pseudorandomized to equate transition probabilities between conditions: Each of the nine possible condition transitions occurred one–two times in the experiment.

All testing was done by one of two female experimenters in a separate, quiet room of the respective day care or primary school. The experiment lasted approximately 15 min. The videos were presented on a laptop using Presentation (Version 13.0, Neurobehavioral Systems, Inc., Berkeley, CA; www.neurobs.com) and had an approximate visual angle of 10°.

After a short warm-up phase, in which the experimenter became familiar with the child, the child sat on a chair at a table with the laptop on it. The experimenter sat to the right of the child and asked whether he or she wanted to play a game of watching short movie clips of actions on a computer. The child was told that in the movies an actress was pretending to perform actions, but the objects were missing, as if they were invisible. The game was to guess what action the actress was pretending to do. If the child agreed to participate. the experimenter initialized the experiment.

The experimenter initiated each trial manually by button press as soon as she directed the children's attention to the screen. After a short presentation of a fixation cross (500 ms), the video presentation and the audio recording started. The video was followed by a fixation cross, and the experimenter asked the child, "Did you recognize the action? What was the person doing?" Depending on the answer, there were three options for how to continue: (a) After a correct response, the experimenter gave positive verbal feedback and initiated the next trial. (b) After a false response, the experimenter said: "Could it also be a different action? Would you like to see the video again and guess one more time?" If the child answered "yes," the video was repeated. If the child answered "no," the experimenter initiated the next trial. (c) If the child gave no response, the experimenter asked whether he or she wanted to see the action again. If the child answered "yes," the video was repeated. If the child answered "no," the experimenter initiated the next trial. Based on this procedure, each video was repeated maximally three times. The number of repetitions was used as a second dependent variable to test whether the children needed fewer (or more) repetitions to recognize an action when the context was compatible (or incompatible). The first three trials were practice trials (washing hands, kneading dough, and painting in compatible, incompatible, and neutral settings, respectively). The practice trials were identical for all children and were not statistically analyzed.

Control Study

To verify that the children were familiar with the actions and able to name them, we conducted a control study immediately after the main experiment. This time, the actions were shown in their natural way, that is, including the involved objects. All actions took place in compatible contexts. The actions were shown in the same order as in the main experiment and only once per trial. After the trials of the main experiment, the experimenter explained the control study by saying, "Let's watch the actions once again, but this time the actress is doing the actions with real objects. Do you want to tell me again what she is doing?"

Postsession Survey

Parents of 92 children participated in a postsession survey, which they completed on paper, via e-mail, or via telephone. The parents judged how often the child performs and observes the 18 different actions (parameters: motor familiarity and perceptual familiarity) using this 4-point Likert scale: 0 (*never*), 1 (*rarely*), 2 (*sometimes*), and 3 (*often*). Because the two parameters were correlated with each other (mean $r = .5 \pm .02$ *SEM*), $t(83) = 19.02$, $p < .001$, we collapsed the two parameters in the subsequent analysis by computing the mean of the two ratings for each action and participant (action familiarity hereafter; for separate analyses of the parameters see the online supplemental materials). In addition, we asked the parents how often the child plays pretend games (using the same Likert scale) and how much time the child spends watching TV (hours per week; for an analysis of these parameters see the online supplemental materials).

Analysis

During the experiment, the button presses of the experimenter coded the relevant information about correctness of the responses and the number of repetitions. The experimenter also coded whether the given responses during the experiment were correct. This was done for each case, that is, for each video repetition of each trial (4,617 cases in total). In addition, the verbal responses of the children were recorded and subsequently transferred into written form by the respective other experimenter (who did not test the respective child). A third independent experimenter evaluated the correctness of written responses. The immediately delivered responses were compared with the written responses to control for interrater reliability. The interrater reliability was computed using Cohen's kappa and had a value of $\kappa = .957$. Cases that were judged inconsistently ($N = 126$; 2.74%), as well as invalid cases, that is, cases where the child was inattentive ($N = 21$; .45%), were excluded from the final sample. One of the actions (sharpening a pencil) was consistently mistaken as "screwing" and was therefore also excluded from the analysis. In total, 4,278 cases (2,590 trials) were analyzed.

Effects on the correctness of responses were analyzed using generalized linear mixed effects models (GLMM) as implemented by the lme4 package of R (Bates, Maechler, Bolker, & Walker, 2015). The children's responses (correct, false) were analyzed as a binomial variable. Effects on the number of video repetitions were analyzed using linear mixed effects models (LMM) as implemented by the nlme package of R (Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2016). In all analyses, the models included a random intercept for participants. For the main analyses of context effects on action recognition, the start models included the following fixed factors: Contextual Compatibility (compatible, incompatible, neutral), Age (4-, 5-, 6-, 7-, 8-year-olds), and Action Category (kitchen actions, playing actions), as well as all interactions involving Contextual Compatibility. Action Category was included to test whether contextual associations are stronger between kitchen actions and kitchens compared to playing actions and playrooms. To analyze whether the children's familiarity with the actions interacts with context effects, we included the variable action familiarity of the postsession rating in the mixed effects model. The start model therefore included the fixed factors Contextual Compatibility, Age, Action Category, action familiarity, and all interactions involving Contextual Compatibility. This analysis was performed with a subset of children for which ratings could be collected ($N = 92$). The fixed factors Age and action familiarity were z-transformed prior to data analysis. In each analysis, the model that optimally fitted the data was identified by stepwise comparison of GLMMs via ANOVAs.

Results

Results of the Control Study

To establish that children can identify the selected actions under normal circumstances we conducted a control study in which the natural counterparts of the pantomime actions were shown. Recognition rates of the control study are reported in Table 1. In all age groups, actions were recognized with high accuracy (all age groups: >97%) demonstrating that children of all age groups were familiar with the presented actions. Recognition accuracies positively correlated with age, $r(153) = .177$, $p = .029$.

Context Effects on Action Recognition

The GLMM of correctness of the children's responses to action recognition revealed significant fixed effects for Contextual Compatibility, Age, and Action Category (Akaike's information criterion [AIC] = 3,303.1; $N_{\text{observations}} = 2{,}590$; $N_{\text{participants}} = 153$). No interactions were observed (comparison to start model: AIC = 3,308.9; $p = .702$). Actions were recognized more often when they took place in compatible contexts compared to incompatible or neutral contexts (see Table 2). The absence of interaction between Contextual Compatibility and Age suggests that context effects were present and similarly strong in all age groups. For visualization, we also computed the mean recognition rates for the three context conditions in each age group (see Figure 2). In addition, the effect of Action Category demonstrates that kitchen actions were recognized significantly better than were playing actions (see Figure 3). There was no evidence for differentially strong context effects for kitchen and playing actions suggesting that the strength of context–action associations was similar for both action categories.

Additionally, we analyzed the number of video repetitions for correctly recognized actions using an LMM. Overall, 84.7% of actions were recognized after the first presentation, 14.4% after the second presentation, and .9% after the third presentation (mean repetition rate = 1.15 ± .03 *SEM*). The LMM of video repetitions revealed no significant fixed effects.

Interaction of Contextual Compatibility and Action Familiarity

In a secondary analysis we tested whether action familiarity interacts with the strength of the context effect on action recognition. The GLMM of responses to action recognition showed significant fixed effects for Contextual Compatibility, Age, Action Category, and the Action Familiarity × Contextual Compatibility interaction (AIC = 1,972.6; $N_{\text{observations}} = 1{,}554$; $N_{\text{participants}} = 92$; see Table 3). All other factors and interactions were not part of the model (comparison to start model: AIC = 1,976.8; $p = .434$). The Action Familiarity × Contextual Compatibility interaction indicates that performance in action recognition improved with increasing action familiarity for actions taking place in incompatible and neutral but not in compatible settings (see Table 3). For visualization, we computed the mean recognition rates for the three context conditions and each level of action familiarity (see Figure 4).

In a second step, we investigated the direction of that interaction in more detail to test whether context effects were stronger for familiar or unfamiliar actions. More precisely, we tested two opposing hypotheses: First, action familiarity might strengthen the association between actions and contextual settings because the actions were observed or executed in their typical setting with high frequency. In this case, context effects should be stronger for familiar actions. Alternatively, if action familiarity is low (and hence action knowledge is sparse), contextual information might become a particularly useful source of information to support action recognition. In this case, context effects should be stronger for unfamiliar actions. To compare the strengths of context effects for familiar versus unfamiliar actions, we first transformed the parameter action familiarity into a two-level variable (low = never + rarely + sometimes; high = often). We then computed recognition rates (correctly recognized actions divided by the total number of actions) for each participant, action familiarity level, and Contextual Compatibility level. Next, we estimated the context effects for each participant and action familiarity level by computing the differences between the recognition rates of (a) compatible and incompatible, (b) compatible and neutral, and (c) neutral and incompatible settings, respectively. Figure 5 shows that context effects were stronger for actions with low versus high action familiarity. Because the data were not equally distributed, we used a Wilcoxon signed-ranks test to determine the significance of the differences between high and low action familiarity. For the recognition rate difference compatible–incompatible, the median rank of low familiarity was significantly higher than the median rank of high familiarity ($z = 1{,}923$; $p < .017$). For the recognition rate difference neutral–incompatible, the median rank of low familiarity was marginally significantly higher than the median rank of high familiarity ($z = 1{,}293.5$; $p < .09$). For the recognition rate difference compatible–neutral, ranks for low versus high action familiarity did not differ significantly ($z = 1{,}494$; $p <$

Table 1
Results of the Postsession Survey (Ratings for Perceptual and Motor Familiarity) and Control Study (Recognition Rate)

Variable	4-year-olds	5-year-olds	6-year-olds	7-year-olds	8-year-olds
N (survey)	8	24	21	29	17
Perceptual familiarity	2.52 (.07)	2.59 (.03)	2.65 (.04)	2.68 (.03)	2.63 (.04)
Motor familiarity	1.90 (.11)	2.08 (.04)	2.29 (.05)	2.39 (.04)	2.34 (.05)
Control study (recognition rate)	.97 (.01)	.98 (.0)	.99 (.0)	.99 (.0)	.99 (.0)

Note. Mean rating values for perceptual familiarity and motor familiarity were based on the Likert scale: 0 (*never*), 1 (*rarely*), 2 (*sometimes*), and 3 (*often*). Standard errors of mean are given in parentheses.

Table 2
Fixed Effects in the GLMM of Action Recognition for the Context Effect During Development, Including AIC of the Competing Model Without the Respective Fixed Factor and p for the ANOVA for the Model Comparison

Fixed effect	Estimate	*SE*	*z*	$p_{\text{fixed factor}}$	$\text{AIC}_{\text{model}}$	p_{model}
(Intercept)	.42	.08	5.15	2.60E−07		
Context					3,372.6	<2E−16
Incompatible vs. compatible	−.82	.1	−8.03	1.00E−15		
Neutral vs. compatible	−.64	.1	−6.33	2.50E−10		
Age	.42	.04	9.76	<2E−16	3,380.1	<2E−16
Action category	−.63	.08	−7.52	5.50E−14	3,358.7	3.10E−14

Note. GLMM = generalized linear mixed effects model; AIC = Akaike's information criterion; ANOVA = analysis of variance.

.43). In summary, these results suggest that contextual information was particularly exploited when actions were less familiar.

Discussion

This study investigated the effect of context–action compatibility on action recognition in 4- to 8-year-old children. Kitchen-typical and playroom-typical actions were videotaped in kitchens, playrooms, and against a neutral white background. All actions were implemented as object-free pantomimes to avoid confounds by context–object associations.

In each age group, compatible contextual settings facilitated action recognition. The size of this effect did not differ across age levels, suggesting that children integrate contextual settings in action observation at the age of 4 and that this effect does not change until the age of 8. Notably, the context effect interacted with action familiarity: Compatible settings were particularly effective when children were presented with less familiar actions, that is, when perceptual or motor experience with an action was sparse.

Development of Context–Action Associations

The contextual compatibility effects in this experiment were in a similar range in all age groups, indicating that context–action associations started to form and become effective before the age of 4, possibly as soon as children observed the actions in their typical environments. Moreover, the consistency of the context effect suggests that the strength and effectiveness of context–action associations is robust between 4 and 8 years of age. However, our findings do not answer the question at which time point in child development contextual information is integrated in action recognition. Recent evidence has suggested that infants recognize actions as being goal-directed from about 6.5 months on (Csibra, 2008; Kamewari et al., 2005; Sodian et al., 2004). Twelve-month-olds interpret two temporally related actions as being connected by an overarching goal, demonstrating that children at this age integrate temporal context in action observation (Woodward & Sommerville, 2000), which suggests that functionally effective connections between actions and contextual settings may develop around the first year of age, too. However, it remains to be investigated whether toddlers younger than 4 indeed integrate contextual information into action recognition to the same extent as do older children.

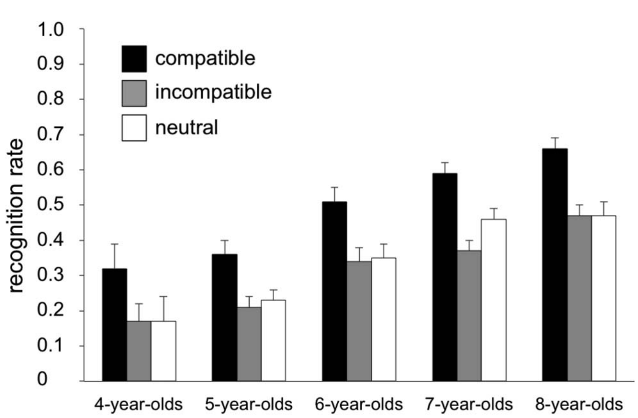

Figure 2. Mean recognition rates (correctly identified actions) for contextual compatibility for each age group. Error bars indicate standard error of mean.

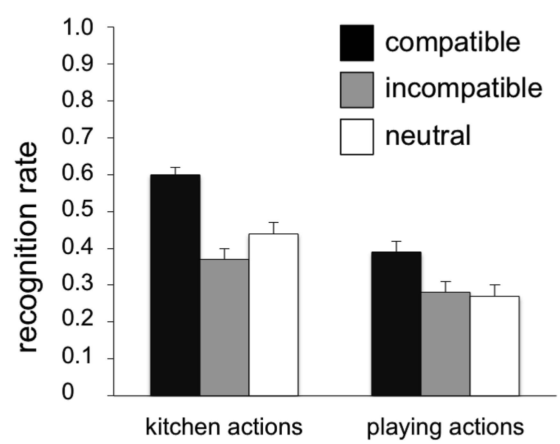

Figure 3. Context effects on recognition rates for each action category separately. Contextual compatibility effects were significant for both action categories: Kitchen actions were recognized more often when they took place in kitchens (compared to playrooms and neutral settings), playing actions were recognized more often when they took place in playrooms (compared to kitchens and neutral settings). Error bars indicate standard error of mean.

Table 3
Fixed Effects in the GLMM of Action Recognition for Action Familiarity, Including AIC of the Competing Model Without the Respective Fixed Factor and p of the ANOVA for the Model Comparison

Fixed effect	Estimate	*SE*	*z*	$p_{\text{fixed factor}}$	$\text{AIC}_{\text{model}}$	p_{model}
(Intercept)	.32	.10	3.04	.002		
Context					2,004.2	1.9E−08
Incompatible vs. compatible	−.78	.13	−5.81	6.2E−09		
Neutral vs. compatible	−.49	.13	−3.73	1.9E−04		
Age	.41	.06	7.14	9.1E−13	2,013.5	5.6E−11
Action category	−.70	.11	−6.31	2.7E−10	2,011.4	1.7E−10
Interactions					1,977.0	.015
Compatible Context × Action Familiarity	−.09	.10	−.92	.357		
Incompatible Context × Action Familiarity	.23	.10	2.36	.018		
Neutral Context × Action Familiarity	.20	.10	1.92	.054		

Note. GLMM = generalized linear mixed effects model; AIC = Akaike's information criterion; ANOVA = analysis of variance.

Actions were identified more easily when they took place in compatible settings. This finding parallels the results of a recent study in adults that showed enhanced recognition of hardly recognizable actions in compatible compared to incompatible or neutral settings (Wurm & Schubotz, 2016). The results suggest that, in accordance with models of contextual modulation of action (Wurm & Schubotz, 2012, 2016) and object recognition (Bar, 2004), contextual settings preactivate associated action knowledge and thereby restrict the number of expectable actions. Context–action associations may develop following frequency-based Hebbian learning (Hebb, 1949; Munakata & Pfaffly, 2004): Observation of actions in their typical settings results in coactivation of settings and actions and, hence, strengthened neural links between the two representations. Once these associations are formed, activation of the setting enhances the excitability of associated action information, which, in case of compatibility, results in increased likelihood to activate the to-be-identified action by the perceived action kinematics.

It is interesting that the facilitation effects observed in Wurm and Schubotz (2016) and in this study selectively affected the accuracy of action recognition. By contrast, the speed of action recognition was typically affected by context in an interfering way: Adults take longer to give correct responses to action recognition in incompatible compared to compatible and neutral settings (Wurm & Schubotz, 2012). Interference effects are suggested to reflect a conflict in integrating an action into overarching action goals associated with the incompatible context. Such interference should not substantially affect the correctness of recognition of the action itself but rather slow down the response following action recognition (Wurm & Schubotz, 2012, 2016). Future studies could elucidate the development of

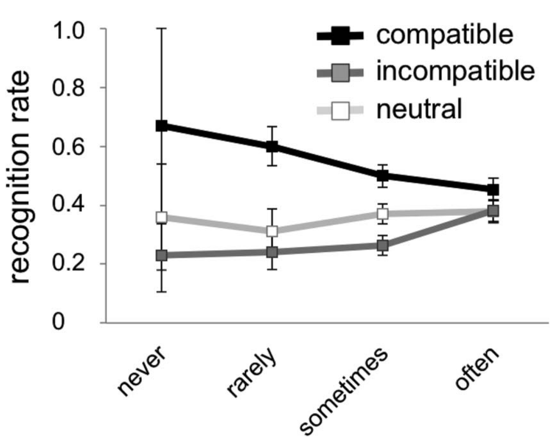

Figure 4. Interaction of context effects with action familiarity. Mean recognition rates for actions that were never, rarely, sometimes, or often observed or executed (collapsed for analysis; see the online supplemental materials for separate plots for motor and perceptual familiarity effects). Error bars indicate standard error of mean. Note that error bars differ between the rating levels because ratings were not equally distributed (see the online supplemental materials for the number of cases for each cell).

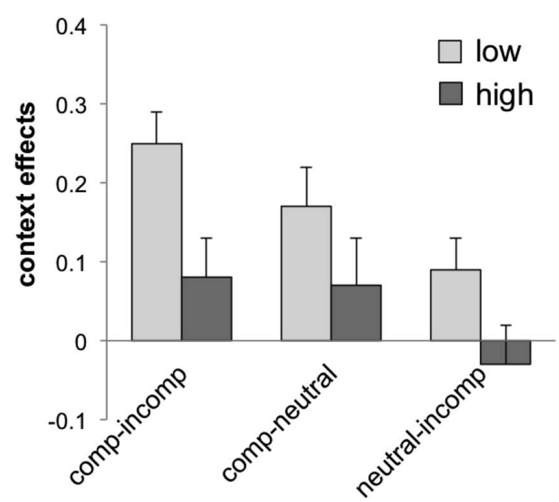

Figure 5. Comparison of context effects (recognition rate differences compatible–incompatible compatible–neutral, neutral–incompatible) for low (never + rarely + sometimes) versus high (often) action familiarity. Error bars indicate standard error of mean. Comp = compatible; incomp = incompatible.

higher level action goal inference by investigating context–action interference effects on the speed of action recognition.

Action Familiarity Interacts With the Size of Context Effects

Although the effect of contextual compatibility was not modulated by age, we did observe an interaction of contextual compatibility with action familiarity: Context effects were stronger for familiar compared to unfamiliar actions, and notably, familiarity improved recognition performance for actions in incompatible and neutral, but not compatible, settings.

Generally, the efficiency of action recognition was expected to improve with increasing familiarity with the action: The more often an action has been either observed or executed, the richer the memory of the corresponding movement kinematics and the stronger the link to the respective action concept should be (Hunnius & Bekkering, 2014). As outlined in the introduction, action familiarity might interact with contextual compatibility in two possible ways. One, the context–action associations are more established for familiar actions and therefore lead to stronger context effects for high versus low action familiarity. Or two, contextual information is particularly exploited when the action is unfamiliar, which should lead to stronger context effects for low versus high action familiarity. Our findings support the latter interpretation: The difference between actions in compatible and incompatible settings was more pronounced for low versus high action familiarity, suggesting that children particularly profited from compatible contexts when they had either no or only a little perceptual or motor experience with the action.

Note that we selected actions that were generally familiar for children of all age groups. As a consequence, the familiarity ratings we obtained were not equally distributed across the Likert scale (only 1.5% and 12.1% of actions were never or rarely observed/executed, respectively). The effect of action familiarity on action recognition should therefore be treated with some caution. What was most striking is that we observed the expected increase of recognition rates only when actions took place in incompatible or neutral settings (see Figure 4A). By contrast, in compatible settings we did not find a positive effect of action familiarity on action recognition. Rather, children seemed to recognize not more but fewer actions the more they were familiar with them. Because we selected mostly familiar actions in our study, we cannot rule out putative artifacts due to the unequal rating distribution. However, the interaction of action familiarity with contextual compatibility is worth considering because it might point to distinct cognitive mechanisms of exploiting context information for the recognition of familiar versus unfamiliar actions. For example, it is possible that contextual information was integrated not only at the level of the action itself (e.g., kitchen—cracking egg) but also at higher levels that represent overarching action goals, which additionally enhances the excitability of the to-be-identified action in a top–down manner (e.g., kitchen—cooking—cracking egg; see also Wurm & Schubotz, 2016). Contextual integration at higher levels might become particularly recruited when actions are unfamiliar and hard to recognize. This hypothesis is generally in line with the finding that context effects were particularly strong for unfamiliar actions. However, the interaction of action familiarity and contextual compatibility should be investigated in more detail by covering a broader range between familiar and unfamiliar actions.

Conclusions

Contextual factors, such as the rooms in which actions take place, are largely neglected in the study of the development of action observation. Here, we show that children between 4 and 8 years of age effectively integrated contextual information in action recognition. This finding informs current theories of action recognition development and supports positions that emphasize the importance of contextual cues for children's ability to recognize actions and to infer underlying intentions (Hunnius & Bekkering, 2014). Notably, contextual facilitation was strongest for unfamiliar actions, suggesting that context is particularly helpful for action identification when children have only little familiarity with the actions. This observation suggests that the integration of contextual cues from the environment is flexible and depends on what information is most useful for action recognition.

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Appendix

List of Actions Used in the Experiment

Kitchen actions	Playing actions
Cracking an egg	Looking at a picture book
Rolling out dough	Building a tower with bricks
Dishing food	Driving with a toy car
Filling a glass	Gluing with a glue stick
Using a knife and fork	Cutting with scissors
Opening a bottle	Dealing out game cards
Stirring in a saucepan	Throwing dice
Cutting vegetables	Drawing
Spreading butter on bread	Sharpening a pencil

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