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Research article

Duration judgments in children and adolescents with and without mild intellectual disability

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ABSTRACT

Background: While the ability to measure time correctly is crucial for adaptation to the external physical and social environment, to date, research on timing ability and its development in individuals with intellectual disability (ID) is unfortunately remarkably scarce.
Aims: In the present study, we investigated the ability of individuals with mild ID to estimate durations and the development of this ability from 11 to 19 years, in comparison to typically developing (TD) individuals.
Methods and procedures: Participants with mild ID and TD participants matched on chronological age completed two temporal tasks: (1) a temporal bisection of auditory stimuli, in which they had to decide whether arbitrary stimulus duration was more similar to the short (200 ms) or the long (800 ms) standard previously learned, and (2) a temporal categorization of familiar actions, in which short, medium or long target durations had to be paired with one of three comparison action durations.
Outcomes and results: Temporal performance was systematically impaired in participants with mild ID. Moreover, the temporal impairment increased with age in the bisection task but not in the categorization task.
Conclusions and implications: These findings suggest that the ability to estimate durations develops at a slower pace in individuals with mild ID compared to TD individuals.

What this paper adds?

Although professionals agree that intellectual disability (ID) affects timing, very little research investigated this effect, and no study has explicitly focused on individuals with mild ID, representing the majority ID. The present study is the first to experimentally examine the ability of individuals with mild ID from late childhood to young adulthood to estimate durations, which is a crucial ability for becoming independent and autonomous and performing everyday activities successfully. More precisely, we examined their ability to make a judgment about the duration of discrete short arbitrary stimuli presented briefly a few times (bisection task) and of longer familiar actions (categorization task). In both tasks, we found a developmental lag in the capacity to estimate durations in individuals with mild ID compared to typically developing (TD) individuals. Moreover, the individuals with mild ID's sensitivity to duration increased with age, from 11 to 19 years of age, while their capacity to categorize familiar action durations remained stable with age. These findings give a novel insight into the sensitivity to duration among individuals with mild ID which could help to improve the effectiveness of clinical and/or educative interventions for this clinical population.

1. Introduction

Intellectual Disability -ID- (American Association on Intellectual Developmental Disabilities, 2010; American Psychiatric Association, 2013) or Intellectual Development Disorder (World Health Organization International, 2018) is one of the main neurodevelopmental disorders. It is characterized by both a significant impairment in general functioning (in particular, reasoning, planning, abstract thinking, judgment and learning) updated by standardized clinical assessments, and adaptive functioning deficits, hindering the ability to respond adequately to the

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requirements of socio-cultural and independence. Without support, deficits in adaptive functioning limit individuals' ability to live their everyday life, in particular in communication, social participation, self-determination and autonomy. ID is thought to affect about 1–3 % of the world's population, with 85% of them having a mild ID (Maulik et al., 2011; McKenzie et al., 2016). People with mild ID not only have intelligence quotient (IQ) scores between 50 and 74, but also are slower in all areas of conceptual development, social and daily living skills (for a review see Pattel et al., 2018). Although mild ID can be caused by genetic or environmental factors, it is estimated that in 80% of cases, it is called idiopathic, in other words, the cause is unknown (INSERM, 2016).

Timing is one conceptual skill, that can also be perceived as a part of adaptive behavior skills, impaired in individuals with ID (American Association on Intellectual Developmental Disabilities, 2010), as supported by clinical observations (e.g., Gibello, 2009; Owen and Wilson, 2006). In addition, the ability to measure time correctly is crucial for adaptation to the external physical and social environment (Buhusi and Meck, 2005). Indeed, as each event and behavior unfold over time (e.g., speaking, cooking, playing, crossing the street safely), accurate duration estimation is essential for becoming independent and autonomous and for performing everyday activities successfully. Despite its significance, to date, research on timing ability and its development in individuals with ID is unfortunately remarkably scarce. Notable exceptions are studies of Janeslätt et al. (2008, 2009, 2010, 2019), who investigated time-processing ability in children with different disabilities including ID, but without focusing specifically on duration judgments.

The main objective of the studies conducted by Janeslätt and colleagues was to develop a time measurement tool for children with disabilities to facilitate the planning of effective interventions in daily time management for these populations. Thus, they developed the Kit for Assessing Time Processing Ability -KaTid-to measure three timing components: time perception (experience of time), time orientation (location in time) and time management (allocating time to activities). The results showed that children with disabilities were significantly older compared to TD children with the same pattern of temporal processing abilities, suggesting that the former might mature in the three timing components at a slower pace (Janeslätt et al., 2010). Based on these findings, it remains however premature to conclude with certainty that there is a developmental lag, although children with mild ID follow the same developmental sequence of timing capacities. One major limitation of Janeslätt et al.‘s studies concerns the mixed panel of participants, which comprised children with different severity levels of ID (mild and moderate) that can be combined with related disorders, such as attention deficit hyperactivity disorder (ADHD), or autism spectrum disorder (ASD). Numerous studies have demonstrated that children with ASD (e.g., Allman and DeLeon, 2009; Gil et al., 2012; Isaksson et al., 2018) and children with ADHD (e.g., Hwang et al., 2010; Lee and Yang, 2019; Yang et al., 2007) show deficits in time perception. Consequently, it appears very difficult, even impossible, to isolate the specific effect of mild ID from that of other related disorders on timing capacity. In sum, it must be recognized that the ability of individuals with mild ID to estimate duration, and the development of this ability, is still mostly unknown. It is now acknowledged that individuals can estimate duration, at least to some degree, as of birth (Brannon et al., 2004; De Hevia et al., 2014). Only a few months old, infants can indeed discriminate close stimulus durations (e.g., Provasi et al., 2011; VanMarle and Wynn, 2006). Nevertheless, mechanisms to accurately measure durations become more efficient through infancy and childhood. In particular, sensitivity to duration (variance) in a bisection task increases with age to reach an adult-like level at about 8–9 years (Droit-Volet, 2013, 2016). In the bisection task, participants were initially familiarized with two standard durations, one short and the other long (e.g., 200 ms and 800 ms in our study)and were then required to judge whether a probe duration (equal to the standard durations or intermediate durations) is more similar to the short or the long standard duration. These developmental findings provide a useful reference framework for comparing the temporal performance of individuals with mild ID.

In addition to processing very short durations in everyday life (e.g., when speaking), children also have to deal with longer events, lasting several minutes or even hours (e.g., watching a cartoon). To examine the ability of individuals with mild ID to estimate the duration of familiar events, we used the temporal categorization task recently developed by Rattat and Tartas (2017). In this task, short, medium, or long target durations must be paired with one of three comparison action durations (short, medium, or long). These authors observed a definite improvement in the capacity to categorize familiar durations from 3 to 8 years of age and also from 8 years of age to and young adulthood. In other words, the ability to understand that several different events can share the same duration is present at an early age and develops further from childhood to adulthood. Rattat and Tartas (2017), therefore, suggested that children can use the duration of familiar actions to organize their experiences and representations of events from the age of 3 years. How does this temporal skill develop in children/adolescents with mild ID? In the current state of knowledge, the answer to this question is still unclear. The KaTid contains, among others, 14 items designed to measure the perceived time duration of daily activities with the instructions “Point at the picture of the activity that takes long (vs. short) time to do” (Janeslätt et al., 2008). However, although children with disabilities performed on these items just as well as did younger TD children (Janeslätt et al., 2008), as reported above, the limited and unbalanced sample of children of different ages and diagnoses in this study restricted the conclusion that might be drawn at this stage regarding individuals with mild ID's ability to estimate the duration of familiar events. Clinical observation provided by carers nevertheless reported a real difficulty with judging time duration experienced by individuals with ID (Owen and Wilson, 2006).

The aim of the current study was to examine the ability of individuals with mild ID aged between 11 and 19 years to estimate durations accurately. We expected that they would follow the same developmental sequence of performance as do TD individuals, but with an age delay. In the temporal bisection task, we therefore expected no age-related change in time mean accuracy, and an increase with age in time sensitivity in individuals with mild ID but not in TD (the younger TD participants would have already reached an adult-like level of sensitivity to duration). Time sensitivity in individuals with mild ID would also be systematically lower compared to that of TD participants of the same age but did not differ from that of younger TD participants (i.e., aged between 5 and 10 years). As for the bisection task, an age-related increase between the ages of 11 and 19 in the ability to estimate and categorize daily action durations should be observed only in individuals with mild ID but not in TD individuals. In Rattat and Tartas (2017) study, the 8-year-olds' percentage of accurate temporal categorization exceeded 70%, which suggests that an adult-like level of performance should be reached over the next few years, thus explaining why we expected no age-related increase in temporal performance in the TD participants in the present study. In other words, we hypothesized that an adult-like level would be reached at an earlier age in TD individuals than in individuals with mild ID. Furthermore, we also expected that the percentage of accurate temporal categorization in individuals with mild ID was systematically lower compared to that of TD participants of the same age but did not differ from that of younger TD participants (i.e., aged between 5 and 10 years).

2. Method

2.1. Participants

The main characteristics of the final sample (n = 168) are presented in Table 1. Twenty-one participants aged 11–13 years (9 girls and 12 boys; mean age = 12.3, *SD* = .99), 21 participants aged 14–15 years (6 girls and 15 boys; mean age = 14.6, *SD* = .66) and 21 participants aged 16–19 years (13 girls and 8 boys; mean age = 17.2, *SD* = .95) with mild

Table 1. Main characteristics of the final sample.

Condition	Age	Range	Mean (SD)	Number	% girls
TD	5–7 years	5.0–6.92	5.8 (.67)	21	57
	8–10 years	7.99–9.93	8.9 (.66)	21	52
	11–13 years	10.6–13.1	12.3 (.80)	21	52
	14–15 years	13.7–15.5	14.6 (.70)	21	33
	16–19 years	16.0–18.9	17.2 (.92)	21	57
ID	11–13 years	10.6–13.5	12.3 (.99)	21	43
	14–15 years	13.8–15.5	14.6 (.66)	21	29
	16–19 years	16.0–18.9	17.2 (.95)	21	62

TD, typically developing; ID, intellectual disability.

ID were recruited from ten medico-social establishments in the south west of France (i.e., Occitanie). To participate in the study, on the one hand, a precise medical diagnosis of the child/adolescent's mild ID had to be documented in his/her record at the Departmental Home for Disabled Persons (MDPH) and, on the other hand, the clinical staff of the establishments had to validate each diagnosis. The participants had to attain an IQ between 50 and 74 (INSERM, 2016). As previously explained, the present study focused on idiopathic mild ID. The criteria for exclusion were thus either the etiology (Down syndrome) or diagnosed associated neurodevelopmental disorders (in particular, ASD and ADHD).

From primary and secondary schools and university in the south west of France, 21 chronological age-matched participants from each age group were selected for participation (11–13 years: 11 girls and 10 boys; mean age = 12.3, *SD* = .80; 14–15 years: 7 girls and 14 boys; mean age = 14.6, *SD* = .70; 16–19 years: 12 girls and 9 boys; mean age = 17.2, *SD* = .92). The participants' age was appropriate to their grade level. Moreover, we also recruited 42 additional TD younger children: 21 children aged 5–7 years (12 girls and 9 boys; mean age = 5.8, *SD* = .67) and 21 children aged 8–10 years (11 girls and 10 boys; mean age = 8.9, *SD* = .66). We also recruited 42 additional TD younger children: 21 children aged 5–7 years (12 girls and 9 boys; mean age = 5.8, *SD* = .67) and 21 children aged 8–10 years (11 girls and 10 boys; mean age = 8.9, *SD* = .66).

All participants and parents (for minors), as well as schools and medico-social establishments' director, provided informed consent and all procedures followed the ethical standards of the Ethics Committee for Research (CER) of the University of Toulouse, which approved the present study.

2.2. Materials

A MacBook pro computer controlled all experimental events. For the temporal bisection task, the stimuli to be timed consisted of 500-Hz tones played over the computer speakers. Participants responded by pressing the "S" or "L" key of the computer keyboard. During the training phase, the feedback was given in the form of a smiley, either smiling (correct response) or sad (incorrect response), which was displayed for 2 s in the center of the computer screen. The program used to run the experiment and record the data was written in PsyScope (Cohen et al., 1993). For the temporal categorization task, the three temporal categories of six photographs of familiar actions used were the same as those previously used by Rattat and Tartas (2017) from a set of photographs standardized by Fiez and Tranel (1997). More precisely, there were six short actions (spit a pip out, sneeze, post a letter, blow a candle out, jump, and hang a coat up), six medium ones (have a drink, erase a blackboard, applaud, fold a towel, blow a balloon up, and blow one's nose), and six long ones (eat a slice of cake, sweep the floor, climb a tree, ring someone, sing a song, and brush one's hair). These photographs were divided into three temporal categories based both on adults' time estimations measured on a 5-point scale ranging from 1 (Very short action) to 5 (Very long action) (Bonin et al., 2004) and on 10 8-year-olds' and 10 adults' verbal estimations expressed in conventional time units (see Rattat and Tartas, 2017, for more details). The PowerPoint program was used to present the photographs of selected actions. Responses were made by pointing out the chosen photograph of action on the computer screen and the experimenter manually noted each of them on an answer sheet.

2.3. Design and procedure

Participants were tested individually in a quiet room for 35 min on average. They completed the two temporal tasks in the same order: 1) temporal bisection of arbitrary auditory stimuli and 2) temporal categorization of familiar actions.

The bisection task consisted of two successive phases: training and testing. In the training phase, the participants initially heard five consecutive presentations of the short (200 ms) and the long (800 ms) standard duration. They were then trained to press one key after the short standard and the other one after the long standard, the button press order being counterbalanced. More precisely, they were presented with a series of eight trials -4 trials for each standard duration-presented in random order. A correct response resulted in the presentation of the smiling smiley and an incorrect one in the presentation of the sad smiley followed by the repetition of the trial. The training ended when the participant made eight correct responses. In the testing phase, the participants were required to indicate whether the comparison stimulus duration was more similar to the short or the long standard by pressing S (vs. L) for short and L (vs. S) for long on the keyboard. No performance feedback was given. Participants completed eight blocks of seven trials (a total of 56 trials) – that is one for each of the seven comparison durations (200, 300, 400, 500, 600, 700, and 800 ms). The trials were presented in a random order within each block. The inter-trial interval was also randomly chosen between 1 and 2 s.

The procedure used for the forced-choice temporal categorization task was strictly identical to that developed by Rattat and Tartas (2017). Participants were instructed to pair each target action duration with one of three comparison action durations. When the target action duration was short (e.g., post a letter), the three comparison durations were either the same (e.g., spit a pip out) or longer (e.g., clap (medium), and ring someone (long)). In contrast, when the target action duration was long (e.g., brush one's hair), the three comparison durations were either the same (e.g., eat a slice of cake) or shorter (e.g., blow a balloon up (medium), blow a candle out (short)). Finally, when the target action duration was medium (e.g., erase a blackboard), the three comparison action durations were either the same (e.g., have a drink), longer (e.g., climb a tree), or shorter (e.g., sneeze). For each trial, the four photographs were simultaneously presented on the computer screen -the target action at the top of the screen, and the three comparison actions next to each other at the bottom of the screen-until the participants have indicated their choice. Each action was presented as a target three times in random order, and it was always associated with different comparison actions randomly chosen. Participants first completed three demonstration trials and then a series of 54 trials, with 18 trials for each of the three target action duration categories. The following instructions accompanied the presented photographs of actions: "On the photograph at the top *(the experimenter points out the photograph)*, the woman 'spits a pip out'. On which of the three photographs at the bottom does she do something that lasts for the same time as when she 'spits a pip out'? Is it when she 'eats a slice of cake', or when she 'sneezes', or even when she 'has a drink' (each time, the experimenter names the action and points out the photograph corresponding to the mentioned action)".

3. Results

3.1. Temporal bisection task

To examine temporal bisection performance, we calculated for each participant the point of subjective equality (PSE- Figure 1) and the Weber ratio (WR- Figure 2), applying the regression method to the steepest part of the individual sigmoïdal function presenting the mean proportion of *long* responses (i.e., identification of a stimulus as being more similar to the long standard than to the short one) plotted against the comparisons stimulus durations (for the method, see Church and Deluty, 1977; Wearden, 1991). The PSE is the stimulus duration at which a participant is equally likely to provide a *long* and *short* response. A decrease (vs. increase) in the PSE means that participants were biased to respond more (vs. less) often *long* and thus overestimated (vs. underestimated) durations. The WR corresponds to the difference limen (half the difference between the stimulus giving rise to 75% *long* responses and that giving rise to 25% *long* responses) divided by the PSE. Reflecting the slope of the bisection function, the WR is considered as an index of temporal sensitivity: smaller WR indicates higher temporal sensitivity; conversely higher WR indicates lower temporal sensitivity.

A first analysis of variance (ANOVA) was performed on PSE and WR with age (11–13 years, 14–15 years and 16–19 years) and condition (TV and ID) as between-participants factors. There were no significant effect on the PSE (all Fs < 1). As illustrated in Figure 1, regardless of age, participants with mild ID did not underestimate or overestimate intermediate durations compared to TD participants. In contrast, the factor condition, $F(1, 126) = 54.65$, $p < .0001$, $\eta^2_p = .31$, as well as the factor age, $F(2, 126) = 3.62$, $p = .03$, $\eta^2_p = .06$, were significant for WR, but the interaction effect between these two factors was not significant, $F(2, 126) = 2.33$, $p = .10$. Figure 2 shows a higher WR for participants with mild ID compared to TD participants, regardless of age, suggesting a lower time sensitivity in the former. Moreover, between-age *a posteriori* comparisons with Bonferroni adjustment revealed that, regardless of condition, the mean WR differed significantly between the participants aged 11–13 years and 16–19 years ($p = .025$). The two between-age comparisons including the 14–15 years' group were not significant ($p = .43$ and $p = .68$). The time sensitivity was thus only lower in the youngest than in the oldest age group.

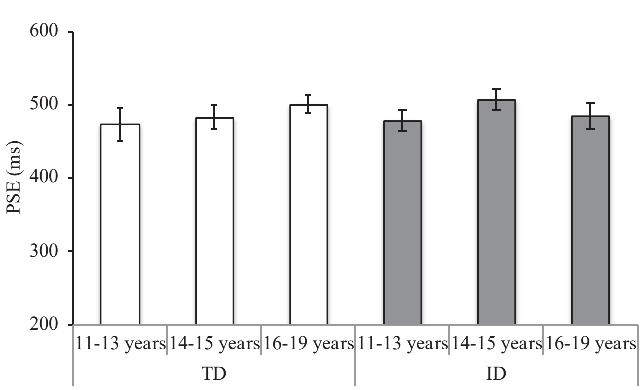

Figure 1. Mean point of subjective equality (PSE) and Weber ratio (WR) for the TD (typically developing) and ID (intellectual disability) participants in the three age groups. Errors bars represent standard error of the means.

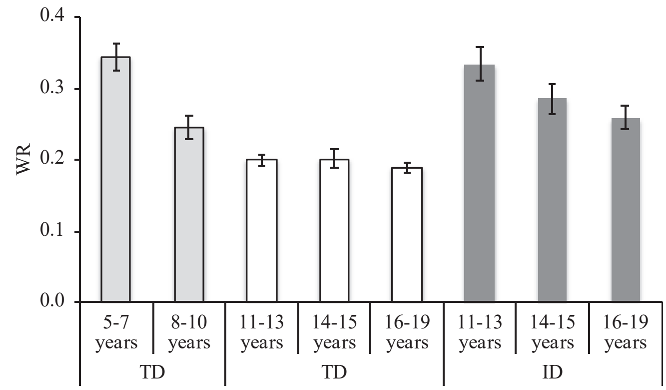

Figure 2. Mean Weber ratio (WR) for the TD (typically developing) and ID (intellectual disability) participants in the different age groups. Errors bars represent standard error of the means.

Although the age × condition interaction effect on WR failed to reach statistical significance, as we assumed, the data picture seems to look different in the two conditions. Therefore, to further examine our hypotheses, we conducted additional statistical analyzes on WR. Whereas no effect of age was observed in the TD condition, $F < 1$, the main effect of this factor reached statistical significance in the ID condition, $F(2, 63) = 3.50$, $p = .036$, $\eta 2p = .11$, because the WR is lower for the older participants aged 16–19 years compared to the younger ones aged 11–13 years ($p = .03$). We then looked at whether the WR for the older participants with mild ID differed from that for TD participants of the same age and younger. It is important to specify here that we adjusted the value of the statistical significance threshold with the Holm method to counteract the problem of multiple comparisons. As expected, at age 16–19 years, the WR of the participants with mild ID was significantly higher compared to that of the TD participants of the same age (.26 vs. .19), $t(40) = -3.75$, $p = .004$, but did not significantly differ from that of the TD children aged 8–10 years, $t < 1$. In the same way, we compared the WR of the youngest participants with mild ID with that of children in the two younger age groups. The *t*-tests for independent samples revealed that the WR was significantly higher for the ID participants aged 11–13 years than for the TD children aged 8–10 years, $t(40) = -3.10$, $p = .012$. In comparison, no significant difference emerged between the ID group and the TD 5–7 years group, $t < 1$.

3.2. Temporal categorization task (familiar actions)

The ANOVA on the mean percentage of accurate temporal categorizations (i.e., when the duration of the chosen comparison action matched that of the target action) with two between-participants factors (age: 11–13 years, 14–15 years and 16–19 years, and condition: TD and ID) and one within-participants factor (target action duration) revealed a significant main effect of condition, $F(1, 120) = 74.92$, $p < .0001$, $\eta 2p = .38$. As illustrated in Table 2, which shows the mean percentage of accurate temporal categorizations and the standard error for the different experimental groups according to the target action duration (short, medium or long), the participants with mild ID made less accurate temporal categorizations compared to the TD ones ($63.43 < 82.36$). The main effect of target action duration was also significant, $F(2, 240) = 63.64$, $p < .0001$, $\eta^2_p = .35$, suggesting that the percentage of accurate temporal categorizations was higher when the target action was short compared to medium and long (a posteriori comparisons with Bonferroni adjustment, both $p < .0001$), as well as when the target action was long compared to medium ($p < .0001$). However, the significant interaction effect between the condition and the target action duration, $F(2, 240) = 6.23$, $p = .002$, $\eta 2p = .05$, indicated that the effect of the target action duration differed according to the condition. In the TD condition, the percentage of accurate temporal categorizations was significantly higher when the target

Table 2. Mean percentages (standard error) of accurate temporal categorizations according to the target action duration in the eight groups.

Condition	Age	Target action duration		
		Short	Medium	Long
TD	5–7 years	73.89 (4.82)	40.55 (4.56)	59.05 (2.95)
	8–10 years	85.98 (3.08)	57.67 (2.96)	73.81 (2.95)
	11–13 years	93.65 (1.81)	76.19 (4.04)	76.72 (2.29)
	14–15 years	91.53 (2.09)	77.25 (3.51)	79.89 (2.43)
	16–19 years	91.80 (1.82)	73.02 (4.27)	81.22 (2.70)
ID	11–13 years	75.40 (4.75)	51.06 (3.42)	65.08 (3.91)
	14–15 years	75.66 (5.09)	50.79 (3.76)	72.49 (3.54)
	16–19 years	70.37 (5.40)	48.15 (4.84)	61.90 (3.86)

TD, typically developing; ID, intellectual disability.

action was short rather than medium or long (a posteriori comparisons with Bonferroni adjustment, $p < .0001$), with no difference between the last two ($p = .56$). On the other hand, in the ID condition, the percentage of accurate temporal categorizations was significantly higher when the target action was short compared to medium ($p < .0001$) as well as when it was long rather than medium ($p < .0001$). The third comparison just failed to reach statistical significance ($p = .057$). The ANOVA did not reveal any other significant effects (age, target action duration x age, condition x age, condition x age x target action duration, all *F*s <1).

Although no main or interaction effect involving the factor age was found, we compared participants with mild ID and younger TD participants aged 5–7 and 8–10 years in the percentage of accurate temporal categorizations. An ANOVA was, therefore, run on the percentage of accurate temporal categorizations with the target action duration as a within-participants factor and the group (ID 11–13 years, ID 14–15 years, ID 16–19 years, TD 5–7 years and TD 8–10 years) as a between-participants factor. As in our previous analyzes, the main effect of target action duration was significant, $F\,(1, 100) = 18\,.92$, $p < .0001$, η2p = .59, revealing that the percentage of accurate temporal categorizations was significantly higher when the target action was short than medium, and when it was long than medium (a posteriori comparisons with Bonferroni adjustment, $p < .0001$). More importantly, the main effect of group was also significant, $F\,(4, 100) = 3.85$, $p = .006$, η2p = .13, indicating that the participants with mild ID aged 16–19 years gave less accurate temporal categorizations compared to the TD participants aged 8–10 years (60.14% vs. 72.49%, $p = .039$). However, they did not give significantly more accurate temporal categorizations compared to the TD participants aged 5–7 years (60.14% vs. 57.50%, $p = 1.0$). No other between-age comparison was significant. The interaction effect between group and age was non-significant, $F < 1$.

Subsequently, we examined the type of temporal categorization error made by participants. Note that the type of temporal categorization error varied according to the target action duration. With short target action durations, the two errors consisted of selecting longer comparison action duration (either medium or long). Conversely, with long target action durations, the two errors consisted of selecting shorter comparison action duration (either medium or short). Finally, with medium target action duration, one error consisted of pairing it with shorter comparison action duration and the other with longer one. Given the above, analyses of participants' temporal categorization errors were conducted for each of the three target action duration categories separately.

For the short target action duration, the ANOVA, conducted on the percentage of temporal categorization errors with two between-participants factors (condition (2) and age (3)) and one within-participants factor (type of error), revealed a significant main effect of condition, $F\,(1, 120) = 34.83$, $p < .0001$, $\eta^2_p = .23$, indicating that participants with mild ID made more errors compared to TD ones (Table 3). The main effect of the type of error was also significant, $F\,(1, 120) = 113.5$, $p < .0001$, $\eta^2_p = .49$. As it can be easily seen in Table 3, the errors concerned more often the choice of a medium comparison (13.49%) than a long one (3.4%). Moreover, there was a significant interaction effect between type of error and condition, $F\,(1, 120) = 16.14$, $p < .0001$, $\eta^2_p = .12$. However, regardless of the type of error, participants with mild ID made more errors compared to TD participants (medium comparison: $t\,(124) = -5.89$, $p < .0001$; long comparison: $t\,(124) = -4.25$, $p < .0001$). Moreover, in both conditions, the participants selected the medium comparison more frequently compared to the long one (TD condition: $t\,(62) = 5.89$, $p < .0001$; ID condition: $t\,(62) = 9.03$, $p < .0001$). No other effect was significant (age, condition x age, type of error × age, type of error × age × condition, all *F*s <1).

For the medium target action duration, the ANOVA only revealed a significant main effect of condition, $F\,(1, 120) = 61.24$, $p < .0001$, $\eta^2_p = .34$, suggesting that participants with mild ID made more errors (25%) compared to TD participants (12.21%). All other effects were not statistically significant (type of error: $F < 1$, age: $F < 1$, type of error × condition, $F\,(1, 120) = 3.10$, $p = .081$, type of error × age: $F\,(2, 120) = 1.25$, $p = .29$, type of error × age × condition: $F\,(2, 120) = 1.44$, $p = .24$).

Table 3. Mean percentage (standard error) of each type of temporal categorization error according to target action duration in the two conditions for the three age groups.

Condition	Age	Target action duration					
		Short		Medium		Long	
		Medium comparison	Long comparison	Short comparison	Long comparison	Short comparison	Medium comparison
TD	11-13 y	5.82 (1.69)	0.53 (.36)	9.79 (2.16)	14.02 (2.50)	0	23.28 (2.29)
	14-15 y	7.67 (1.97)	0.79 (.43)	9.52 (2.14)	13.23 (2.50)	0	20.11 (2.44)
	16-19 y	7.41 (1.81)	0.79 (.58)	14.29 (3.61)	12.43 (2.42)	0.79 (.43)	17.99 (2.65)
ID	11-13 y	19.31 (3.40)	5.29 (1.78)	23.81 (2.63)	25.13 (2.41)	6.35 (1.68)	28.57 (3.24)
	14-15 y	19.84 (3.69)	4.50 (2.25)	29.36 (2.90)	19.84 (2.44)	4.76 (1.85)	22.75 (2.71)
	16-19 y	20.90 (3.20)	8.73 (2.44)	27.25 (3.87)	24.60 (3.40)	9.79 (3.18)	28.31 (2.48)

TD, typically developing; ID, intellectual disability.

As for the short and medium target durations, for the long target action duration, there was a significant main effect of condition, F (1, 120) = 24.04, $p < .0001$, $\eta^2_p = .17$, indicating that the percentage of errors was higher in the ID condition (16.76%) than in the TD one (10.36%). The main effect of the type of error also reached statistical significance, F (1, 120) = 252.75, $p < .0001$, $\eta^2_p = .68$, revealing that participants chose the medium comparison duration (23.5%) more frequently compared to the short one (3.62%). No other significant effects emerged from the ANOVA (age: F (2, 120) = 1.63, $p = .20$, type of error × condition, $F < 1$, type of error × age: F (2, 120) = 1.39, $p = .25$, age × condition: F (2, 120) = 1.79, $p = .17$, type of error × age × condition: $F < 1$).

4. Discussion

The present study dealt with an essential yet very understudied area of investigation: the ability of individuals with mild ID to estimate durations and the development of this ability from late childhood to young adulthood. Our findings are original in that the developmental aspects of duration judgments differed depending on whether participants had to discriminate short arbitrary durations in a bisection task or to categorize familiar actions according to their durations. In the bisection task, the duration sensitivity in participants with mild ID (but not duration accuracy) increased from 11 to 19 years of age, while their capacity to categorize familiar action durations remained stable with age. Nevertheless, for both tasks, temporal performance in the participants with mild ID was systematically not only lower than in the chronological age-matched TD participants but also similar to that obtained by TD children several years younger. In late adolescence and early adulthood (i.e., 16-19 year-olds), the delay in the developmental sequence of the capacity of participants with mild ID to estimate durations seemed greater in the categorization (approximately 11 years) than in the bisection task (about 8 years) compared to TD participants.

The absence of age-related difference in duration accuracy coupled with the age-related improvement in sensitivity to duration observed in participants with mild ID in the bisection task is consistent with previous developmental studies in TD individuals highlighting that from 3 to 25 years, timing remains accurate on average while sensitivity to time improves with age until it reaches an adult-like level at about 8–9 years (for reviews, see Droit-Volet, 2013, 2016). Our findings are original in that they revealed that individuals with mild ID seem to follow the same developmental sequence of duration discrimination capacity as TD individuals, but with an age delay of approximately half their age or a deficit. Furthermore, this delay or deficit seems not to decrease from late childhood to young adulthood. Indeed, participants with mild ID aged 11–13 years and TD children aged 5–7 years did not exhibit a different duration sensitivity level (as measured by the Weber Ratio in the bisection task), as did participants with mild ID aged 16–19 years and TD children aged 8–9 years. Based on data collected in the present study, an absolute conclusion could however not be reached about the existence of a developmental delay or deficit. The question that is remaining is whether such a difference in duration sensitivity between individuals with and without mild ID persists throughout adulthood -thus reflecting a deficit- or progressively decreases, until individuals with mild ID reach a TD adult-like level -thus reflecting rather a delay. Answering this question requires further studies with older adults.

There is nevertheless a crucial question: What causes the developmental delay in duration sensitivity among individuals with mild ID compared to individual without mild ID in the bisection task? Classical internal clock-timing models (Gibbon, 1977; Gibbon et al., 1984; Treisman, 1963; for a review, see also Wearden, 2003) state that perceived duration depends on the number of pulses emitted by a pacemaker and transferred into an accumulator through an attention-controlled switch which closes at the beginning and opens at the end of the stimulus to be timed. The accumulated pulses form a representation of duration, which is stored in working memory and may then be transferred to long-term memory. Within this theoretical framework, timekeeping thus requires directing and maintaining attention to time, which likely implies various cognitive abilities. Recent developmental studies showed that age *per se* is not a significant predictor of variation in the sensitivity to duration in a bisection task, unlike cognitive factors that are associated with age, in particular working memory capacities, processing speed, and attention/concentration (Droit-Volet and Hallez, 2019; Droit-Volet and Zélanti, 2013; Zélanti and Droit-Volet, 2011). The increase with age in sensitivity to duration in the bisection task is therefore caused by the increased effectiveness of cognitive processing of temporal information. This conclusion can be extended to individuals with mild ID insofar as they followed the same developmental increase in sensitivity to duration as TD individuals. However, numerous findings have highlighted that individuals with mild ID showed delays in the development of attention, memory, and executive functions (corresponding to the set of neurocognitive processes involved in goal-directed regulation of thoughts and actions, Diamond, 2013), which are cognitive functions identified as critical to time estimation (e.g., Danielsson et al., 2012; Djuric-Zdravkovica et al., 2010; Henry and MacLean, 2002; Van der Molen, Van Luit, Jongmans and Van der Molen, 2007; for a recent review see also Hronis et al., 2017). We, therefore, suggest that the developmental delay in duration sensitivity between individuals with and without mild ID observed in our study is derived from more limited general cognitive abilities in individuals with mild ID rather than the limitations in the processing of temporal information due to their disability. Further studies are, however, needed to test this hypothesis directly and to clarify the extent to which mild ID individuals' cognitive retardation of various cognitive functions (working memory, attention, and executive functions) is directly linked to the slower development of their sensitivity to duration.

Contrary to the temporal performance of individuals with mild ID in the bisection task, their performance in the categorization task did not improve with age from 11-13 to 16–19 years. More precisely, in both ID and TD participants, we found the same pattern of results: the percentage of accurate temporal categorizations remained stable with age, although systematically lower than in the participants with mild ID, and the least frequent errors consisted of categorizing a short action as a long one and vice versa. In a previous study, Rattat and Tartas (2017) showed that the percentage of accurate temporal categorizations increased with age throughout childhood and continued to rise between 8-year-olds and young adults. In the present study, the absence of an age-related increase in the percentage of accurate temporal categorizations in TD participants, therefore, suggests that an adult-like level would be reached between 8 and 11–13 years of age. In individuals with mild ID, however, the percentage of accurate temporal categorizations in the oldest participants aged 16–19 years was slightly lower than in TD participants aged 8–10 to 11–13 years. It did not differ from the percentage observed in TD participants aged 5–7 years. At first sight, the absence of age-related improvement in their temporal categorization performance from 11-13 and 16–19 years may suggest that they have reached their maximum level of performance (ceiling effect). This also suggests that by the end of adolescence, individuals with mild ID would not yet have reached an adult-like level. More research is necessary to draw definitive conclusion.

The absence of age-dependent increase in the capacity of participants with mild ID to accurately categorize familiar actions according to their duration does not appear to imply that these participants do not possess differentiated representations of the durations of daily actions. First, their percentage of accurate temporal categorizations reached approximately 63.5% for the whole test, which is clearly above chance level, suggesting that for each trial they did not choose between the three comparison actions at random. Second, various findings suggest that memory of action durations develops partially from experience (e.g., Boltz et al., 1998; Tobin and Grondin, 2012, 2015). Although in our study we did not assess the participants' level of prior experience for each of the 18 familiar actions, there is no objective reason to think that individuals with mild ID had less experience during their life with these specific actions compared to TD individuals and consequently that these actions were less familiar to them. We, therefore, assume that they should be able to implicitly judge the durations of actions by comparing familiar actions and differentiate them based on their duration.

In our study, their more mediocre performance can thus come from the cognitive activity involved in the task itself, specifically the categorization activity. Two aspects of categorization must be distinguished, namely the organizational (i.e., how knowledge is organized) and functional (i.e., how this organization is used) aspects. While ID does not appear to have a significant effect on the organizational aspect of the categorization, it does have one on the functional aspect. The results of different studies indeed suggest that it is more difficult for individuals with ID to effectively use categories in a task involving explicit recourse, thus explaining that their performance is lower than that of TD individuals only in tasks involving intentional treatment of categories (Gavornikova-Baligand, 2005; Gavornikova-Baligand and Deleau, 2004; Megalakaki and Yasbek, 2013; Megalakaki et al., 2010). Megalakaki and Yasbek (2013) for example have shown that in a forced-choice task, children with mild ID categorize items in the same way as TD children, while the justifications they gave for the choice they had made differed; in particular they cited category membership less frequently to justify their taxonomic choices[1]. According to the authors, this suggested that children with mild ID have greater difficulty extracting the conceptual invariants needed to mobilize the categories. It should be specified that in this study, as in others that have examined the effect of ID on categorization, the choice of the categorization criterion was left to the participants. In contrast, in our study, the criterion for categorizing familiar actions, that is, the duration necessary to carry out the actions, was given to participants explicitly (in the verbal instructions). However, it was found that despite this difference, in line with previous studies, individuals with mild ID performed lower. Our results, therefore, support the difficulty of exploiting the categorical links between stimuli in individuals with mild ID. Insofar as this functional aspect of categorization is impaired by ID, in further studies, it would be interesting to use different tasks to investigate the capacity to estimate familiar durations in individuals with mild ID. For example, we can use a production task in which the participants have to produce the duration of the familiar actions depicted on photographs via a keypress, like in Rattat and Tartas (2019) study of TD children. This would make it possible to identify more precisely the difficulties in estimating familiar durations by dissociating them from those linked to the categorization activity.

5. Conclusion

Our results highlighted - for the first time - a developmental lag in the capacity to estimate durations in individuals with mild ID, both the capacity to discriminate short arbitrary durations in a bisection task and to categorize the durations of familiar actions. However, between 11 and 19 years of age, their sensitivity to duration increased (in the bisection task) but not their capacity to categorize familiar action durations, suggesting that the developmental difference in the latter task is more pronounced. These findings might be primarily due to the impaired development of cognitive functions identified as critical to the duration estimation in the tasks used (in particular attention, memory, and executive functions). Further work is necessary to look more closely into this. To conclude, insofar as the ability to estimate durations is crucial to becoming independent and autonomous and to performing everyday activities successfully, by improving our understanding of how mild ID can affect this capacity, the present findings could, therefore, guide the development of effective clinical and educative interventions for this clinical population. A deeper understanding of the difficulties and/or atypia in the development of timing abilities in young individuals with mild ID might foster the use of early stimulation of timing behaviors within the framework of their care activities. Professionals could propose various time estimation tasks to individuals with mild ID, with the ambition to more easily adapt to conventional time tools (such as chronometers, timers, clocks). Moreover, care professionals could also build with them -according to their difficulties-ergonomic and functional tools in everyday life (e.g., use of telephone alarms, implementation of visual schedules adapted to home, school or company).

[1] A taxonomic category refers to objects of the same kind grouped according to different types of shared properties, such as name, function, etc (Nelson, 1988). It is the most abstract type of categories.

Declarations

Author contribution statement

A-N. Rattat: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

I. Collie: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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The authors declare no conflict of interest.

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