The Role of Working Memory in Japanese-Speaking Children's Comprehension of Active and Passive Sentences

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1. Introduction

Understanding how children comprehend sentence structure is a central issue in language development. While basic word order is acquired early, comprehension of syntactically complex sentences continues to develop throughout childhood (Bever, 1970), suggesting that factors beyond grammatical knowledge contribute to sentence processing. Working memory (WM), a domain-general resource, supports sentence comprehension by enabling the temporary maintenance and integration of linguistic information (Baddeley & Hitch, 1974). Individual differences in WM capacity are associated with children's performance on syntactically demanding sentences (Daneman & Carpenter, 1980). However, it remains debated whether WM merely constrains language performance or plays a more fundamental role in syntactic development (Melby-Lervåg & Hulme, 2016; Roque-Gutierrez & Ibbotson, 2023).

Passive sentences offer a particularly informative testing ground for examining the role of WM. Across languages, Passives are acquired later than Active sentences and are more difficult to comprehend, likely due to their non-canonical mapping between syntactic positions and thematic roles (Armon-Lotem et al., 2016; Borer & Wexler, 1987). In Japanese, sentence interpretation relies heavily on case markers and verbal morphology that must often be retained in WM until the predicate is encountered. Japanese also distinguishes between Full Passives and Short Passives, which differ in structural complexity and processing demands (Ishikawa & Minai, 2022).

The present study examines how age and WM capacity contribute to Japanese children's comprehension of Active and passive sentences. Four sentence types—Intransitive Actives, Transitive Actives, Full Passives, and Short Passives—are tested in children aged 4 to 6 years. WM capacity is assessed using Forward and Backward Digit Span tasks. Using generalized linear mixed-effects models, we test whether sentence comprehension is better predicted by WM capacity than by

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 Proceedings of the 50th annual Boston University Conference on Language Development, ed. Romi Hill et al., 333-346. Somerville, MA: Cascadilla Press.

chronological age, and whether WM differentially supports Active and Passive sentence types.

2. Theoretical background

2.1. Working memory and sentence comprehension

WM is commonly defined as a limited-capacity system responsible for the temporary storage and manipulation of information necessary for complex cognitive activities, including language comprehension (Baddeley & Hitch, 1974). In sentence processing, WM supports the maintenance of linguistic representations until they can be integrated into syntactic and semantic structures. Evidence from adult studies shows that individual differences in WM capacity predict comprehension accuracy for syntactically complex sentences, including object relative clauses (King & Just, 1991). In children, the WM capacity increases with age (Gathercole et al., 2004), and developmental increases in WM have been linked to improvements in sentence comprehension. However, previous research suggests that the contribution of WM to language processing is not uniform across syntactic structures (Bever, 1970). WM demands vary depending on the degree of non-canonicity, dependency length, and representational complexity of a given sentence (Gordon et al., 2001).

Research on Japanese has provided clear evidence that WM plays a crucial role in sentence comprehension (Mizumoto, 2008). Japanese rely heavily on case markers to signal argument structures, and these markers often cannot be fully interpreted until a predicate is encountered. As a result, children must retain the phonological representations of case markers in WM during incremental processing. The author demonstrated that Japanese-speaking children's comprehension of scrambled sentences is constrained by WM capacity. Children with higher WM capacity perform better when the processing load is reduced by omitting one case marker, suggesting that maintaining multiple case markers simultaneously can overload WM. These findings indicate that WM limitations can directly constrain syntactic interpretation during early development.

Importantly, this line of research suggests that WM primarily supports the maintenance of linguistic information, rather than more complex manipulative operations, during early childhood. This distinction becomes particularly relevant when considering different types of WM measures such as the Forward versus Backward Digit Spans.

2.2. Directionality between working memory and syntax: Evidence from training studies

Recent intervention research has provided important insights into the causal relationship between WM and syntactic development. Roque-Gutierrez et al. (2023) demonstrated that improving 7-year-old children's WM capacity led to measurable gains in syntactic ability, whereas syntactic training did not result in corresponding improvements in WM. This asymmetry strongly suggests that WM serves as a foundational cognitive resource supporting syntactic processing rather than being shaped by linguistic experience alone. Crucially, the study showed that WM training selectively benefited children's performance in syntactic tasks that required the retention of intermediate representations, reinforcing the view that WM supports sentence comprehension by enabling children to maintain linguistic information during incremental parsing. These findings align with the hypothesis that the WM capacity constrains early syntactic processing, particularly for structures that require sustained activation of representations.

2.3. Passive sentence acquisition and cognitive load in Japanese

Passive sentences are acquired later than Active sentences across languages, and Full Passives are more difficult for children to understand than Short Passives (Armon-Lotem, 2016; Borer & Wexler, 1987 among many). In Japanese, previous research has indicated that children's difficulty processing Passives cannot be fully accounted for by grammatical hypotheses alone (Ishikawa & Minai, 2022). However, to the best of our knowledge, there is a lack of direct empirical evidence demonstrating a clear relationship between WM capacity and passive sentence comprehension in Japanese-speaking children.

2.4. Summary

Taken together, previous research suggests that WM capacity plays a critical role in children's sentence comprehension; however, its contribution depends on both the nature of the syntactic structure and the specific WM components involved. Theoretical and empirical evidence converge on the view that WM is related to syntactic processing by enabling the temporary retention of linguistic information during comprehension.

Building on this literature, the present study investigated how WM capacity, as measured by Forward and Backward Digit Spans, relates to Japanese-speaking children's comprehension of Active and Passive sentences. By directly comparing sentence types that differ in syntactic complexity, this study aimed to clarify how WM constraints shape early sentence comprehension and whether WM predicts performance more robustly than chronological age.

3. Research questions and predictions

Based on previous research on WM and sentence comprehension, as well as the theoretical considerations outlined above, this study addresses the following research questions:

3.1. RQ1: How does comprehension of Active and Passive sentences develop with age in Japanese-speaking children?

Previous cross-linguistic studies have shown that Passive sentences are acquired later than Active sentences, and that not all Passive sentences are equally difficult (Armon-Lotem, 2016 among others). However, prior work suggests that age-related improvements in sentence comprehension may not be uniform across syntactic structures, particularly during early childhood (Kidd & Bavin, 2002). Therefore, this study examines whether chronological age predicts improvements in comprehension accuracy for Active and Passive sentences and whether such developmental changes differ across sentence types.

If age functions as a global developmental index, comprehension accuracy should increase with age across different sentence types. Alternatively, if some sentence types have already reached a ceiling performance or developed later than early childhood, age-related effects may be limited or absent under certain conditions.

3.2. RQ2: How does comprehension of Active and Passive sentences develop with working memory capacity, while controlling for age?

Building on evidence that WM capacity constrains sentence processing in both adults and children, this study investigated whether individual differences in WM predict sentence comprehension beyond the effect of chronological age. In particular, this study examined whether WM capacity is differentially related to the comprehension of syntactically simpler Active sentences and more complex passive sentences. To determine whether sentence comprehension was influenced primarily by WM capacity alone or by both capacity and mental manipulation, WM was assessed using Forward and Backward Digit Span tasks.

If WM serves as a proximal cognitive resource for sentence comprehension, a higher WM capacity should be associated with better comprehension performance, even when controlling for age. Furthermore, if early sentence comprehension depends more on maintenance than on the manipulation of information, the Forward Digit Span is expected to predict comprehension more strongly than the Backward Digit Span, particularly for Active sentences.

4. Method

4.1. Participants

Fifty-three Japanese-speaking children participated in this study (37 girls; 20 four-year-olds, 23 five-year-olds, and 10 six-year-olds; M_{age} = 5.26 months, SD = 0.61, Range = 4.17–6.25). All participants were typically developing, with no reported hearing, visual, or developmental impairments, and were raised in monolingual Japanese-speaking environments. Children were recruited from preschools in Japan with parental consent. The study was approved by the institutional ethics committee of Tsuda University (#2403), and verbal consent was obtained from all children prior to participation.

4.2. Tasks and materials

4.2.1. Sentence comprehension task

Children completed a picture–sentence verification task designed to assess their comprehension of four sentence types.

Intransitive Active (Filler)

(1)	Kaeru-ga	Oyoideiru-yo.
	frog-NOM.	swim-PROG.PRES.-PART.
	‘The frog is swimming.’	

Transitive Active

(2)	Kaeru-ga	Saru-o	Hippar-teiru-yo.
	frog-NOM.	Monkey-ACC.	pull-PROG.PRES.-PART.
	‘The frog is pulling the monkey.’		

Full Passive

(3)	Saru$_i$-ga	Kaeru-ni	t_i	Hippar-are-teiru-yo.
	Monkey-NOM.	frog-by		pull-PASS.PRES.-PART.
	‘The monkey is being pulled by the frog.’			

Short Passive:

(4)	Saru$_i$-ga		t_i	Hippar-are-teiru-yo.
	Monkey-NOM.			pull-PASS.PRES.-PART.
	‘The monkey is being pulled.’			

Each condition included 16 Transitive Active trials, 16 Passive trials (eight Full Passive and eight Short Passive), and 32 Intransitive trials as fillers, yielding a total of 64 trials. The sentences were presented auditorily and, for each trial, the children were shown a picture depicting contrasting thematic role assignments. Their task was to judge whether the pictures correctly matched the sentences they heard. All sentences were constructed using familiar nouns and verbs to minimize lexical difficulty: Transitive Vs: *osu* ‘push,’ *hipparu* ‘pull,’ *arau* ‘wash,’ *tsutsuku* ‘poke,’ *hikkaku* ‘scratch,’ *keru* ‘kick,’ *naderu* ‘pat,’ and *kusuguru* ‘tickle,’ Intransitive Vs: *tatsu* ‘stand,’ *neru* ‘sleep,’ *korobu* ‘fall,’ *odoru* ‘dance,’ *hashiru* ‘run,’ *shagamu* ‘squat,’ *oyogu* ‘swim,’ *suwaru* ‘sit down’ (adobted from Ishikawa & Goro, 2017 and Ishikawa et al., 2020). A female native Japanese speaker recorded the audio stimuli. The trial order was randomized. Half of the pictures correctly depict the event referred to in the test sentence (‘Match’ items), while the Agent and Patient were depicted in reverse in the other half of the pictures (‘Mismatch’ items). The position in which the Agent animal appears (left vs. right) was counterbalanced across pictures. The responses were recorded as binary accuracy scores (correct or incorrect).

4.2.2. Working memory task

WM capacity was assessed using a digit span task consisting of two subtests: the Forward Digit Span, which measures the ability to temporarily maintain verbal information, and the Backward Digit Span, which measures the ability to manipulate and reorder information in WM. Digits were presented orally at a fixed pace. In the Forward condition, the children were asked to repeat the digits in the same order; in the Backward condition, they were asked to repeat them in reverse order. Standard scoring procedures were applied, with higher scores indicating a greater WM capacity.

4.3. Statistical analysis

First, to examine how children's sentence comprehension develops with age, we analyzed task performance (correct versus incorrect) using a generalized linear mixed-effects model (GLMM) with a binomial distribution and a logit link function. We included four conditions (Intransitive Active, Transitive Active, Full Passive, and Short Passive), age (*z*-standardized), and their interaction as fixed effects, as well as gender as a covariate. Random intercepts for the participants and task items were also included in the model.

Second, to examine whether WM capacity modulates children's sentence comprehension, we constructed GLMMs independently for the Forward and Backward digit spans. Because the digit span scores had a restricted score range and were not widely distributed, we discretized them into Low and High to facilitate interpretability. Fixed effects included the Condition, WM score (two levels), and their interaction. Age and sex were included as covariates. The random intercepts are the same as those described above.

For these analyses, we used *R* version 4.3.2 (R Core Team, 2023) and the packages of *car* (Fox & Weisberg, 2019), *emmeans* (Lenth et al., 2025), *lme4* (Bates et al., 2015), and *lmerTest* (Kuznetsova et al., 2017). We used the Holm method to adjust the *p*-values for post-hoc comparisons.

5. Results

5.1. Working memory performance

Mean score for Forward Digit Span was 4.58 (SD = 0.82, Range = 3–6), and mean score for Backward Digit Span was 3.38 (SD = 0.84, Range = 2–5). Spearman's rank correlation analyses revealed significant positive associations between age and WM capacity for both measures (Forward span: $r_s = .47, p < .001$; Backward span: $r_s = .57, p < .001$), indicating developmental increases in WM during the preschool years.

Because the digit span scores showed a restricted range and limited dispersion, both Forward and Backward span scores were discretized into Low and High groups for subsequent analyses to facilitate interpretability. The descriptive statistics for each group are summarized in Table 1.

Table 1. Participant characteristics by WM span group.

		Age		Span	
	#Children (#Girls)	*M* (*SD*)	Range	*M* (*SD*)	Range
Forward span group					
Low	25 (15)	4.89 (0.47)	4.17–6.25	3.84 (0.37)	3–4
High	28 (22)	5.58 (0.54)	4.58–6.25	5.25 (0.44)	4–5
Backward span group					
Low	31 (20)	4.99 (0.54)	4.17–6.25	2.77 (0.43)	2–3
High	22 (17)	5.64 (0.50)	4.83–6.25	4.23 (0.43)	4–5

5.2. RQ1: Comprehension of Active/Passive sentences with age

Figure 1 presents descriptive statistics for the relationship between sentence comprehension performance and age. The GLMM revealed a significant main effect of Condition ($\chi^2(3) = 67.63$, $p < .001$), and Condition × Age interaction ($\chi^2(3) = 10.27$, $p = .016$), but not Age ($\chi^2(1) = 1.94$, $p = .16$) and Gender ($\chi^2(1) = 0.31$, $p = .58$). Post-hoc multiple comparisons for condition terms showed that the Intransitive Active was comprehended significantly better than all other sentence types (Transitive Active: odds ratio, $OR = 14.56$, $SE = 7.56$, $p < .001$; Full Passive: $OR = 73.20$, $SE = 39.50$, $p < .001$; Short Passive: $OR = 21.55$, $SE = 11.70$, $p < .001$). Transitive Active was also better than Full Passive ($OR = 5.03$, $SE = 2.84$, $p < .012$), whereas no other pairwise differences reached significance (*p*s > .072).

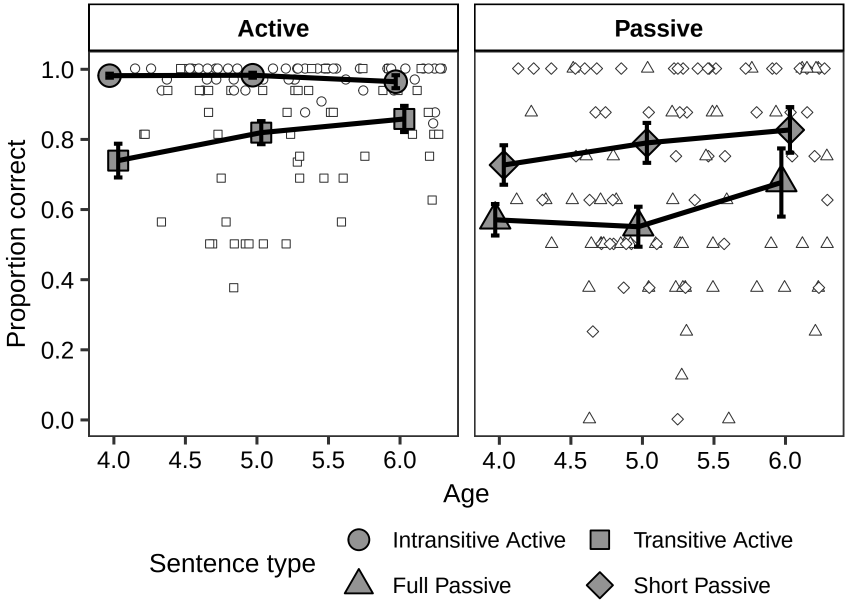

Figure 1. Age-related changes in sentence comprehension
Proportion correct is shown as a function of age for four sentence types. Points indicate individual children's mean accuracy. Filled symbols show the mean across children within each age bin, with error bars representing ±1 *SE*. The same legend applies to the following figures.

Simple slope analyses indicated that only Transitive Active showed a significant age-related improvement in comprehension (difference between −1 *SD* and +1 *SD* age, $OR = 0.45$, $SE = 0.18$, $p = .050$). No significant age-related improvement was observed for Intransitive ($OR = 1.56$, $SE = 0.76$, $p = .36$) or for either type of Passive (Full Passive: $OR = 0.66$, $SE = 0.27$, $p = .30$; Short Passive: $OR = 0.48$, $SE = 0.21$, $p = .10$).

At younger ages (−1 *SD*), Intransitive Active outperformed all other conditions (Transitive Active: $OR = 26.94$, $SE = 15.30$, $p < .001$; Full Passive: $OR = 112.85$, $SE = 66.70$, $p < .001$; Short Passive: $OR = 38.68$, $SE = 22.90$, $p < .001$), and Transitive Active outperformed Full Passives ($OR = 4.19$, $SE = 2.45$, $p = .042$). No significant differences were found among the remaining pairwise comparisons (*p*s > 15). At older ages (+1 *SD*), Intransitive Active remained the most accurately comprehended (Transitive Active: $OR = 7.87$, $SE = 4.30$, $p < .001$; Full Passive: $OR = 47.48$, $SE = 27.00$, $p < .001$; Short Passive: $OR = 12.01$, $SE = 6.93$, $p < .001$;), and Transitive Active was significantly better understood than Full Passive ($OR = 6.03$, $SE = 3.58$, $p = .007$). The other condition pairs were not significantly different (*p*s > .052).

5.3. RQ2: Effects of working memory on sentence comprehension

Figure 2 shows the relationship between Forward Digit Span and sentence comprehension accuracy after controlling for age. The model revealed a robust main effect of Condition ($\chi^2(3) = 70.37$, $p < .001$). The Span group × Condition interaction was also significant ($\chi^2(3) = 16.57$, $p < .001$), whereas the main effect of Span group ($\chi^2(1) = 3.32$, $p = .068$) and Covariates (Age: $\chi^2(1) = 0.10$, $p = .75$; Gender: $\chi^2(1) = 0.66$, $p = .41$) were not significant. Averaged over span group levels, Intransitive was significantly more accurate than all other conditions (Transitive Active: *OR* 14.39, *SE* = 7.50, $p < .001$; Full Passive: *OR* 74.06, *SE* = 40.10, $p < .001$; Short Passive: *OR* 22.13, *SE* = 12.00, $p < .001$), and Transitive Active outperformed Full Passive (*OR* = 5.15, *SE* = 2.91, $p = .011$). Other pairwise comparisons did not reach significance after Holm's adjustment (*p*s > .077).

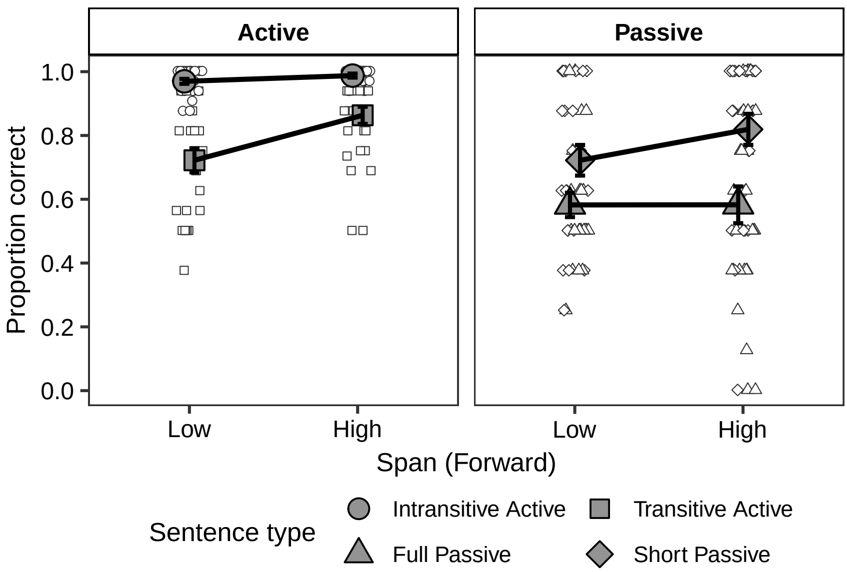

Figure 2. Sentence comprehension as a function of Forward Digit Span

Critically, the interaction reflected that span group differences were condition-specific: Intransitive and Transitive Active sentences demonstrated significant WM-related improvement in comprehension (Low/High odds ratio, Intransitive: *OR* 0.34, *SE* = 0.18, $p = .044$; Transitive Active: *OR* 0.28, *SE* = 0.13, $p = .005$). On the other hand, sentence comprehension did not differ between the Low- and High-span groups for Full Passives (*OR* = 1.00, SE = 0.48, $p = 0.99$) and Short Passives (*OR* = 0.45, *SE* = 0.22, $p = .10$). Thus, a higher Forward span was associated with better performance in Active sentence types but not in Passive sentence types.

Within the Low Forward-span group, the Intransitive condition outperformed all other conditions (Transitive Active: *OR* 15.93, *SE* = 8.55, $p < .001$; Full

Passive: *OR* 43.42, *SE* = 24.50, $p < .001$; Short Passive: *OR* 19.35, *SE* = 10.90, $p < .001$). Differences among the non-Intransitive conditions were not significant (*p*s > .25; e.g., Transitive Active vs. Full Passive: *OR* 2.73, *SE* = 1.59, $p = .25$). In the High group, in addition to the most accurate performance in Intransitive (Transitive Active: *OR* 13.01, *SE* = 7.50, $p < .001$; Full Passive: *OR* 126.32, *SE* = 75.40, $p < .001$; Short Passive: *OR* 25.31, *SE* = 15.20, $p < .001$), Transitive Active was significantly more accurate than Full Passive (*OR* = 9.71, *SE* = 5.76, $p < .001$), and Full Passive was significantly lower than Short Passive (*OR* = 0.20, *SE* = 0.12, $p = .017$). The contrast between Transitive Active and Short Passive movements was not significantly different (*OR* = 1.95, *SE* = 1.17, $p = .27$).

Figure 3 shows the relationship between the Backward Digit Span and sentence comprehension accuracy after controlling for age. For Backward Span, the model again showed a strong main effect of Condition ($\chi^2(3) = 71.14$, $p < .001$), but no main effect of Span group ($\chi^2(1) = 0.30$, $p = .58$) and no Span group × Condition interaction was observed ($\chi^2(3) = 1.44$, $p = .69$). As in the other models, covariates were not significant (Age: $\chi^2(1) = 0.92$, $p = .34$; Gender: $\chi^2(1) = 0.35$, $p = .55$). Averaged over span group levels, Intransitive was significantly more accurate than all other conditions (Transitive Active: *OR* = 13.89, *SE* = 7.18, $p < .001$; Short Passive: *OR* = 20.11, *SE* = 10.80, $p < .001$; Full Passive: *OR* = 69.37, *SE* = 37.30, $p < .001$), and Transitive Active outperformed Full Passive (*OR* = 5.00, *SE* = 2.82, $p = .013$). Other pairwise comparisons did not reach significance after Holm's adjustment (*p*s > .067). Overall, the discretized Backward Span did not explain the additional variance in sentence comprehension beyond the sentence-type differences captured by Condition.

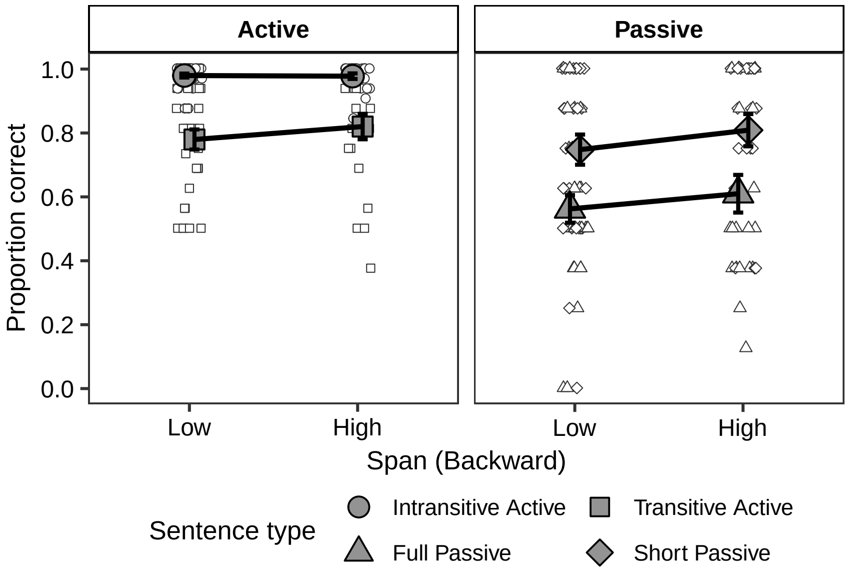

Figure 3. Sentence comprehension as a function of Backward Span

6. Discussion

With respect to RQ 1, the results showed that age-related improvements in sentence comprehension during preschool years were limited and structure-specific. Although a significant condition × age interaction was observed, simple slope analyses revealed that only the Transitive Actives showed reliable improvement with age. The consistently high performance of Intransitive Actives across age groups suggests a ceiling effect, indicating that the structure was mastered relatively early. In contrast, the absence of age-related improvements in Passives suggests that the acquisition of Passive constructions, particularly Full Passives, may extend beyond preschool. While no significant difference between Short and Full Passives was observed overall, the consistent advantage of Transitive Actives over Full Passives across age levels supports the view that Full Passives represent the most challenging structure in this paradigm.

These findings suggest that the present age range may be insufficient to capture the full developmental progression across sentence types used in the study, highlighting the need for future studies including a broader age range. Rather than showing uniform developmental gains, different sentence types appear to follow distinct developmental trajectories, with some structures stabilizing early and others developing later.

RQ 2 addressed whether WM capacity predicted sentence comprehension when age was controlled. The results clearly demonstrate that WM, particularly the Forward Digit Span, functioned as a significant modulating factor, whereas the Backward Digit Span did not. The Forward Digit Span was selectively associated with improved comprehension of Active sentences (both Intransitive and Transitive), even after controlling for age. In contrast, neither Short nor Full Passives showed reliable improvement as a function of the Forward Span. These findings indicate that increases in WM capacity during early childhood primarily support comprehension of syntactically simpler structures.

Backward Digit Span, which is assumed to reflect the ability to manipulate information in WM, does not explain the additional variance in sentence comprehension. This dissociation suggests that early sentence comprehension relies more heavily on the maintenance of linguistic representations than on manipulation.

Importantly, these findings align with recent intervention research showing a close relationship between WM and children's syntactic abilities (Roque-Gutierrez & Ibbotson, 2023). In the present study, the Forward Digit Span, which reflects WM capacity rather than executive manipulation, was the measure most closely linked to sentence comprehension, which is consistent with the view that the ability to maintain linguistic representations plays a critical role in early syntactic processing.

The absence of robust WM effects for Passive sentences suggests that Passive comprehension in Japanese may be constrained by factors beyond general WM capacity, at least during preschool years. One possibility is that the processing demands for Passive sentences exceed those that can be supported by increases in

WM capacity alone, thus requiring additional linguistic or cognitive maturation. Notably, within the high Forward-span group, Short Passives showed higher comprehension accuracy than Full Passives, suggesting that reduced structural complexity may facilitate comprehension when sufficient WM capacity is available. However, the overall lack of a strong WM effect indicates that Passive comprehension may depend on mechanisms that develop later, such as advanced syntactic representations and language-specific processing strategies. Alternatively, the absence of Backward-span effects may partly reflect the limitations of the current dataset, as Backward Digit Span scores showed a restricted range, and relatively few children achieved high scores. More generally, it is possible that the contribution of WM manipulation abilities to Passive comprehension emerges later in development or that more linguistically specific WM measures would better capture such effects.

Taken together, these findings suggest that WM capacity is a more proximal and sensitive predictor of sentence comprehension than chronological age during early childhood, although its effects are selective. WM relates to the comprehension of simpler, more canonical structures, whereas more complex constructions such as Passives may require additional developmental changes beyond increases in WM capacity. These results support the view that cognitive and linguistic development interact asymmetrically; WM provides essential support for sentence processing, but improvements in syntactic knowledge do not necessarily feed back into domain-general cognitive capacity.

This study had several limitations. First, the restricted range of digit-span scores may have reduced the sensitivity of detecting WM effects, particularly for Backward Spans. Second, digit span tasks may underestimate the contribution of language-specific WM to sentence comprehension. Future studies should include older children and employ a wider range of WM measures, including linguistic-based span tasks, to further clarify the developmental relationship between WM and Passive sentence comprehension.

7. Conclusion

This study examined how Japanese children's comprehension of Active and Passive sentences was related to their chronological age and WM capacity. The results showed that age-related improvements during early childhood were limited and structure specific, with reliable developmental gains observed only for Transitive Active sentences. In contrast, WM capacity, particularly the Forward Digit Span, predicted the comprehension of Actives even when age was controlled for, whereas the Backward Digit Span showed no such effect. Passive sentence comprehension was not reliably associated with either age or WM in this age range, suggesting that the acquisition of Passive constructions, especially Full Passives, may depend on developmental factors beyond general WM capacity or may develop later. Taken together, these findings support the view that WM serves as a foundational cognitive resource for early sentence comprehension primarily by supporting the maintenance of linguistic representations, whereas complex syntactic structures may require additional linguistic or cognitive maturation. This pattern is consistent with recent training evidence demonstrating a causal influence of WM on syntactic development and highlights the importance of distinguishing between different components of WM when modeling language development.

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Proceedings of the 50th annual Boston University Conference on Language Development

edited by Romi Hill, Xinhan Jiang,
Danutham Worapipat, and Aditya Yedetore

Cascadilla Press   Somerville, MA   2026

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ISSN 1080-692X
ISBN 978-1-57473-047-0 (2 volume set, paperback)

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