Cataphora processing in agrammatic aphasia: Eye movement evidence for integration deficits

Introduction

Individuals with agrammatic aphasia show selective impairments in comprehending syntactically complex sentences with long-distance dependencies such as WH-dependencies. In the literature, conflicting results have been reported with respect to the source of such deficits. Representational accounts claim that these deficits are attributed to impaired linguistic phenomenon critical to WH-dependency computation [1-3]; whereas, processing resource accounts suggest that general processing resource limitations such as impaired working memory capacity or generally slowed processing underlie comprehension difficulty [4-6]. Lexical Integration Deficit Hypothesis [LIDH, 7-8] suggests that the process of integrating lexical items into the syntax is impaired. Recent eye-tracking-while-listening studies show that agrammatic listeners process complex sentences normally in real time, but still are unable to understand sentence meaning. These findings suggest that comprehension difficulty arises from failure to integrate hierarchical grammatical structures and lexical elements. The present study further evaluates the LIDH by investigating patients' processing of cataphoric dependencies, another type of long-distance dependency that relies on integration processes for sentence comprehension.

Cataphoric Dependencies involve a long-distance relation between a pronoun and its antecedent, where the pronoun (dependent element) precedes the antecedent (licensing element), as illustrated in (2a). Structurally, the relation between the pronoun and the antecedent is governed by Binding Condition C [9]: the pronoun-antecedent relation is impossible when a pronoun c-commands it antecedent as in (2b).

(2) a. After he$_i$ read the paper, John$_i$ went to the meeting.

b. *He$_i$ read the paper after John$_i$ went to the meeting.

Previous studies showed that cataphoric and WH- dependencies are processed similarly: in both structures, the parser actively searches for the licensing element, and the search processes respect grammatical constraints [10-12]. That is, upon encountering the dependent element, the parser starts searching for its licensing element to establish the dependency as soon as possible. Importantly, this search is grammatically constrained; therefore, in examples like (2), the parser tries to associate the pronoun and the antecedent in (2a), but not (2b). In previous studies, the active search effect is shown using the gender mismatch paradigm: during online reading of examples like (3), eye-gaze durations were longer when the gender specification of the pronoun (e.g., *she-female*) and the closest potential antecedent (e.g., *the boy-male*) mismatched (the so-called Gender Mismatch Effect (GMME)), indicating the parser's 'surprised' at failing to complete the dependency in the closest available antecedent position [11-13].

(3) a. When he$_i$/*she$_i$ was at the party, the boy$_i$ cruelly teased the girl.

b. He/she was at the party when the boy cruelly teased the girl.

Some recent studies on cataphora processing also have found that lexical information, such as stereotypical or definitional gender information is crucial for the GMME [13, 14]. These studies investigated cataphora processing in healthy young and older population, manipulating gender specification types of the antecedent. They found that the GMME is observed only with definitional gender nouns in (4a), where the gender of the antecedent is unambiguously specified, but not for stereotypical nouns in (4b) where the gender of the antecedent is ambiguously marked, but understood stereotypically either as male or female [13, 14]. Such results suggest that the gender interpretation of the antecedent is affected by the preceding pronoun/reflexive, i.e., when the pronoun/reflexive is male (*himself*), a stereotypical noun (e.g., *minister*) is interpreted as male, but when the pronoun/reflexive is female, the stereotypical noun is interpreted as female. This finding indicates that processing stereotypical nouns requires additional integration costs: readers have to integrate the gender specification of the antecedent based on the gender of the pronoun. In this way, cataphora involves dependency formation and lexical processes such as gender checking and integrating gender information into a sentential context.

(4) a. After reminding himself$_i$/*herself$_i$ about the letter the king$_i$ left London.
b. After reminding himself$_i$/herself$_i$ about the letter the minister$_i$ left London.

This study examined the integration of grammatical and lexical information during cataphora processing in agrammatic and control participants using eye-tracking self-paced reading paradigm, since eye movements are preserved in agrammatic patients. Additionally, eyetracking enables us to examine patients' online cataphora processing, even when they fail to comprehend sentences offline.

Method

Participants: Six individuals with clinical diagnosis of agrammatic aphasia (WAB AQ: 70.8-89.6), and 15 young healthy control speakers participated in the study. All were native English speakers, and their vision and hearing were within normal limits. There was no reported history of neurological or psychological disorders. **Table 1** lists the agrammatic patients' clinical and demographic information.

Materials: In an eye-tracking self-paced reading experiment, the c-command relation between the pronoun and antecedent (non-c-command/dependency vs. c-command/no-dependency), the gender between the pronoun and its potential antecedent (gender match vs. mismatch), and the gender specifications (stereotypical vs. definitional) were manipulated as in (5a-h). Eighty sets of experimental sentences were created and divided into two separate scripts, in addition to 160 fillers. Participants were tested using either script.

(5) a/b. Yesterday after he$_i$/*she$_i$ read the paper, the king$_i$ happily went to the meeting.
c/d. Yesterday he/she read the paper after the king happily went to the meeting.
e/f. Yesterday after he$_i$/she$_i$ read the paper, the minister$_i$ happily went to the meeting.
g/h. Yesterday he/she read the paper after the minister happily went to the meeting.

According to LIDH, it was anticipated that both healthy and agrammatic participants would show a GMME for the dependency-mismatch-definitional condition (as in (5b)), but not in any c-commanded no-dependency conditions. However, unlike controls, agrammatic participants were predicted to also show a GMME in the dependency-mismatch-stereotypical condition (as in (5f)), due to their deficits in integration processing, since processing such sentences requires revision of gender stereotype using prior contextual gender information in order to build a dependency between the pronoun and its gender mismatched stereotypical antecedent.

Data analysis: A set of eyetracking measures (first fixation, first pass, regression-path and second pass reading times) recorded in the critical antecedent (the king/minister) and spillover (adverb) regions were analyzed using linear mixed effect models. Offline comprehension scores between two groups were analyzed using Mann-Whitney U test.

Results

Results are shown in **Table 2-4**. Importantly, the analyses of the regression-path reading times revealed a significant interaction of *c-command x gender x noun type* in the critical region for the healthy controls, associated with a GMME in the dependency/mismatched/ definitional condition, but not in the stereotypical condition (Figure 1). A similar, albeit marginally significant interaction was found in the spillover region for the patient group (Figure 2), followed by a highly significant interaction in the second-path reading time measure (Figure 3). However, GMMEs in both definitional and stereotypical c-command/mismatched conditions were found, with a greater and later GMME in the stereotypical compared to the definitional conditions. Additionally, the aphasic participants showed chance-level performance across all conditions.

Conclusions

These findings indicate that the patient group exhibited similar eye movement patterns to that of the control group when processing definitional nouns in cataphoric dependencies. However, unlike controls, they showed processing difficulties associated with gender ambiguity. These patterns support the LIDH. These findings will be discussed with regard to alternative theories of agrammatic sentence comprehension as well as their clinical applicability. (1165 words)

References

1. Grodzinsky, Y. (1986). Language deficits and the theory of syntax* 1. *Brain and Language, 27*(1), 135-159.
2. Grodzinsky, Y. (2000). The neurology of syntax: Language use without Broca's area. *Behavioral and brain sciences, 23*(1), 1-21.
3. Mauner, G., Fromkin, V. A., & Cornell, T. L. (1993). Comprehension and acceptability judgments in agrammatism: Disruptions in the syntax of referential dependency. *Brain and Language*.
4. Burkhardt, P., Mercedes Pinango, M., & Wong, K. (2003). The role of the anterior left hemisphere in real-time sentence comprehension: Evidence from split intransitivity* 1. *Brain and Language, 86*(1), 9-22.
5. Hartsuiker, R. J., & Kolk, H. H. J. (1998). Syntactic facilitation in agrammatic sentence production. *Brain and Language, 62*(2), 221–254.
6. Love, T., Swinney, D., & Zurif, E. (2001). Aphasia and the time-course of processing long distance dependencies. *Brain and Language, 79*(1), 169-170.
7. Choy, J. J., & Thompson, C. K. (2010). Binding in agrammatic aphasia: Processing to comprehension. *Aphasiology, 24*(5), 551-579.
8. Thompson, C. K., & Choy, J. J. (2009). Pronominal resolution and gap filling in agrammatic aphasia: Evidence from eye movements. *Journal of psycholinguistic research, 38*(3), 255-283.
9. Chomsky, N. (1981). Lectures on Government and Binding. *Dordrecht: Foris*.
10. Stowe, L. A. (1986). Parsing WH-constructions: Evidence for on-line gap location. *Language and Cognitive Processes, 1*(3), 227-245.
11. Kazanina, N., Lau, E. F., Lieberman, M., Yoshida, M., & Phillips, C. (2007). The effect of syntactic
constraints on the processing of backwards anaphora. *Journal of Memory and Language, 56*(3), 384-409.
12. van Gompel, R. P. G., & Liversedge, S. P. (2003). The influence of morphological information on cataphoric pronoun assignment. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(1), 128.
13. Kreiner, H., Sturt, P., & Garrod, S. (2008). Processing definitional and stereotypical gender in reference resolution: Evidence from eye-movements. *Journal of Memory and Language, 58*(2), 239-261.
14. Radvansky, G., Lynchard, N., & von Hippel, W. (2008). Aging and stereotype suppression. *Aging, Neuropsychology, and Cognition (Neuropsychology, Development and Cognition, 16*(1), 22-32.

Table 1

Agrammatic participants' demographic information and testing results

Subject ID	Age	Gender	Education	Yrs post onset	WAB			WAB-reading		NAVS		Narrative speech			
					AQ	**AC**	**F**	**RSC**	**RC**	**SPPT**	**SCT**	**WPM**	**MLU**	**%GS**	**RCS**
NF1	35;6	F	18	5;3	82.5	7.55	5	40	20	63	70	55.29	7.63	65	.33
	LH CVA														
NF2	52;2	F	13	6;6	70.8	8.8	4	32	20	63	70	31.76	7.06	56.25	.45
	LH CVA														
NF3	52;8	M	16	7;9	71.1	8.35	9	36	20	50	86.67	41.15	5.44	15.15	.39
	LH CVA														
NF4	58;8	M	21	7;5	89.6	10	5	40	20	80	100	58.19	8.07	78.57	.65
	RH CVA														
NF5	65;2	M	20	12;9	71.7	8.45	4	40	20	16.7	83.3	73.48	4.80%	18.75	.78
	LH CVA														
NF6	40;9	M	16	6;11	72.8	8.2	4	40	20	73.3	66.7	25.96	5.5	30	0
	LH CVA														

Note: WAB=Western Aphasia Battery; AQ=Aphasia Quotient; F= Fluency; AC= Auditory Comprehension; WAB-reading= WAB reading supplementary tests; RSC= Reading Sentence Comprehension; RC= Reading commands; NAVS= Northwestern Assessment of Verbs and Sentences; SPPT= Sentence Production Priming Test; SCT= Sentence Comprehension Test; WPM= words per minute; MLU= Mean length of utterance; %GS= % Grammatical sentences; %CS= ratio of complex sentences to simple sentences; LH= left hemisphere; RH= right hemisphere; CVA= cerebrovascular accident.

Table 2

Young Normals' reading time data in the critical region

			First fixation		**First pass**		**Regression path**		**Second pass**	
			mean	SD	mean	SD	mean	SD	mean	SD
dependency	definitional	match	206.50	56.10	290.83	119.11	320.28	143.15	293.41	149.08
		mismatch	203.73	63.23	319.94	149.68	375.77	194.07	430.89	265.21
	stereotypical	match	196.74	55.98	272.32	116.58	303.43	144.55	332.40	231.06
		mismatch	200.51	56.99	300.17	138.64	337.51	172.38	348.17	207.50
no dependency	definitional	match	194.17	49.72	297.81	153.67	419.96	222.11	429.24	220.65
		mismatch	191.02	52.72	287.02	141.04	413.49	220.13	425.62	252.25
	stereotypical	match	192.41	52.11	289.43	141.12	427.71	244.55	434.05	265.69
		mismatch	190.08	47.93	294.03	141.58	422.01	219.21	424.28	253.19
Linear Mixed Effect Regression			*df; F*	*p*	*df; F*	*p*	*df; F*	*p*	*df; F*	*p*
dependency			(1, 2152); 17.98	.00*	(1, 2184); 0.40	.53	(1, 2112); 100.24	.00*	(1, 1231); 33.06	.00*
Ntype			(1, 2152); 2.79	.10	(1, 2184); 2.81	.09#	(1, 2112); 1.26	.26	(1, 1231); 0.56	.45
gender			(1, 2152); 0.23	.63	(1, 2184); 4.61	.03*	(1, 2112); 5.01	.03*	(1, 1231); 6.80	.01*
dependency * Ntype			(1, 2152); 1.20	.27	(1, 2184); 2.44	.12	(1, 2112); 4.26	.04*	(1, 1231); 0.78	.38
dependency * gender			(1, 2152); 0.48	.49	(1, 2184); 7.13	.01*	(1, 2112); 8.66	.00*	(1, 1231); 9.66	.00*
Ntype * gender			(1, 2152); 0.62	.43	(1, 2184); 0.36	.55	(1, 2112); 0.36	.55	(1, 1231); 5.69	.02*
dependency * Ntype * gender			(1, 2152); 0.37	.54	(1, 2184); 0.50	.48	(1, 2112); 0.41	.52	(1, 1231); 4.64	.03*

Table 3

Patients' reading time data in the critical region

			First fixation mean	SD	First pass mean	SD	Regression path mean	SD	Second pass mean	SD
dependency	definitional	match	206.06	51.73	323.43	144.34	469.20	282.43	898.90	636.00
		mismatch	222.29	65.04	329.62	141.97	465.55	321.62	892.77	676.18
	stereotypical	match	236.50	72.76	371.80	174.30	443.52	228.76	729.81	431.10
		mismatch	213.89	58.52	348.60	154.90	430.16	222.52	845.71	572.58
no dependency	definitional	Match	211.91	58.44	370.27	191.88	479.08	236.06	806.62	505.04
		mismatch	216.02	62.09	373.67	188.01	573.06	309.96	1087.35	763.40
	stereotypical	match	220.38	62.50	414.10	214.26	475.77	215.19	687.26	422.96
		mismatch	204.27	56.68	358.12	208.94	528.34	288.81	836.95	534.62
Linear Mixed Effect Regression			*df; F*	*p*	*df; F*	*p*	*df; F*	*p*	*df; F*	*p*
dependency			(1, 769); 2.21	.14	(1, 766); 7.57	.01*	(1, 727); 10.00	.00*	(1, 633); 0.08	.78
Ntype			(1, 769); 1.13	.29	(1, 766); 3.40	.07#	(1, 727); 1.94	.16	(1, 633); 10.08	.00*
gender			(1, 769); 1.09	.30	(1, 766); 1.80	.18	(1, 727); 2.73	.10	(1, 633); 8.56	.00*
dependency * Ntype			(1, 769); 2.07	.15	(1, 766); 0.57	.45	(1, 727); 0.03	.87	(1, 633); 0.69	.41
dependency * gender			(1, 769); 0.10	.75	(1, 766); 0.47	.49	(1, 727); 4.35	.04*	(1, 633); 3.02	.08#
Ntype * gender			(1, 769); 11.24	.00*	(1, 766); 2.93	.09#	(1, 727); 0.43	.51	(1, 633); 0.00	.96
dependency * Ntype * gender			(1, 769); 1.12	.29	(1, 766); 0.33	.56	(1, 727); 0.16	.69	(1, 633); 1.88	.17

Table 4

Young Normals' eye data in the spillover region

			First fixation		First pass		Regression path		Second pass	
			mean	SD	mean	SD	mean	SD	mean	SD
dependency	definitional	match	215.30	56.07	250.77	83.97	277.17	118.04	259.99	131.38
		mismatch	213.61	58.56	242.93	85.34	321.28	195.89	328.41	181.67
	stereotypical	match	211.58	56.64	235.84	75.21	285.88	139.07	272.32	138.69
		mismatch	214.38	59.69	239.62	83.86	288.32	141.21	327.66	187.69
no dependency	definitional	match	213.78	60.14	235.92	77.71	298.83	152.68	319.24	165.58
		mismatch	220.04	67.03	243.98	87.84	267.92	115.00	275.36	127.03
	stereotypical	match	225.35	59.62	258.72	86.63	285.18	119.06	322.57	195.68
		mismatch	217.77	55.38	236.24	72.07	266.02	104.34	338.27	190.36
Linear Mixed Effect Regression			*df; F*	*p*	*df; F*	*p*	*df; F*	*p*	*df; F*	*p*
dependency			(1, 2178); 4.73	.03*	(1, 2114); 0.16	.69	(1, 2024); 4.94	.03*	(1, 1038); 2.54	.11
Ntype			(1, 2178); 0.39	.53	(1, 2114); 0.05	.82	(1, 2024); 2.62	.11	(1, 1038); 3.42	.06#
gender			(1, 2178); 0.00	.98	(1, 2114); 1.69	.19	(1, 2024); 0.02	.89	(1, 1038); 5.16	.02*
dependency * Ntype			(1, 2178); 1.46	.23	(1, 2114); 5.49	.02*	(1, 2024); 0.12	.72	(1, 1038); 1.69	.19
dependency * gender			(1, 2178); 0.06	.81	(1, 2114); 0.53	.47	(1, 2024); 15.43	.00*	(1, 1038); 13.03	.00*
Ntype * gender			(1, 2178); 0.85	.36	(1, 2114); 1.77	.18	(1, 2024); 1.48	.22	(1, 1038); 1.22	.27
dependency * Ntype * gender			(1, 2178); 3.26*	.07#	(1, 2114); 8.80	.00*	(1, 2024); 4.72	.03*	(1, 1038); 2.98	.08#

Table 5

Patient's eyedata in the spillover region

			First fixation		**First pass**		**Regression path**		**Second pass**	
			mean	SD	mean	SD	mean	SD	mean	SD
dependency	definitional	match	226.02	72.30	283.95	125.38	348.07	209.49	577.87	395.91
		mismatch	247.12	74.32	307.98	133.52	468.83	339.32	596.22	428.47
	stereotypical	match	244.97	73.14	289.49	110.03	333.83	173.76	522.50	305.36
		mismatch	243.33	70.62	301.59	116.68	371.79	185.32	737.07	613.44
no dependency	definitional	match	253.38	73.33	309.77	108.80	347.76	149.74	644.19	462.89
		mismatch	261.03	93.98	293.97	91.39	349.00	161.88	714.35	513.34
	stereotypical	match	264.21	99.59	344.91	153.11	356.04	162.76	639.81	401.39
		mismatch	250.06	73.69	313.28	131.74	357.33	168.50	612.69	386.64
Linear Mixed Effect Regression			*df; F*	*p*	*df; F*	*p*	*df; F*	*p*	*df; F*	*p*
dependency			(1, 794); 9.01	.00*	(1, 769); 5.02	.03*	(1, 731); 3.61	.06#	(1, 569); 1.38	.24
Ntype			(1, 794); 0.45	.50	(1, 769); 2.32	.13	(1, 731); 2.56	.11	(1, 569); 0.02	.89
gender			(1, 794); 0.33	.56	(1, 769); 0.10	.75	(1, 731); 7.44	.01*	(1, 569); 3.35	.07#
dependency * Ntype			(1, 794); 0.47	.50	(1, 769); 2.47	.12	(1, 731); 4.68	.03*	(1, 569); 1.61	.20
dependency * gender			(1, 794); 1.34	.25	(1, 769); 5.63	.02*	(1, 731); 6.98	.01*	(1, 569); 1.58	.21
Ntype * gender			(1, 794); 3.95	.05*	(1, 769); 0.62	.43	(1, 731); 1.96	.16	(1, 569); 0.43	.51
dependency * Ntype * gender			(1, 794); 0.00	.97	(1, 769); 0.01	.91	(1, 731); 1.96	.16	(1, 569); 3.78	.05*

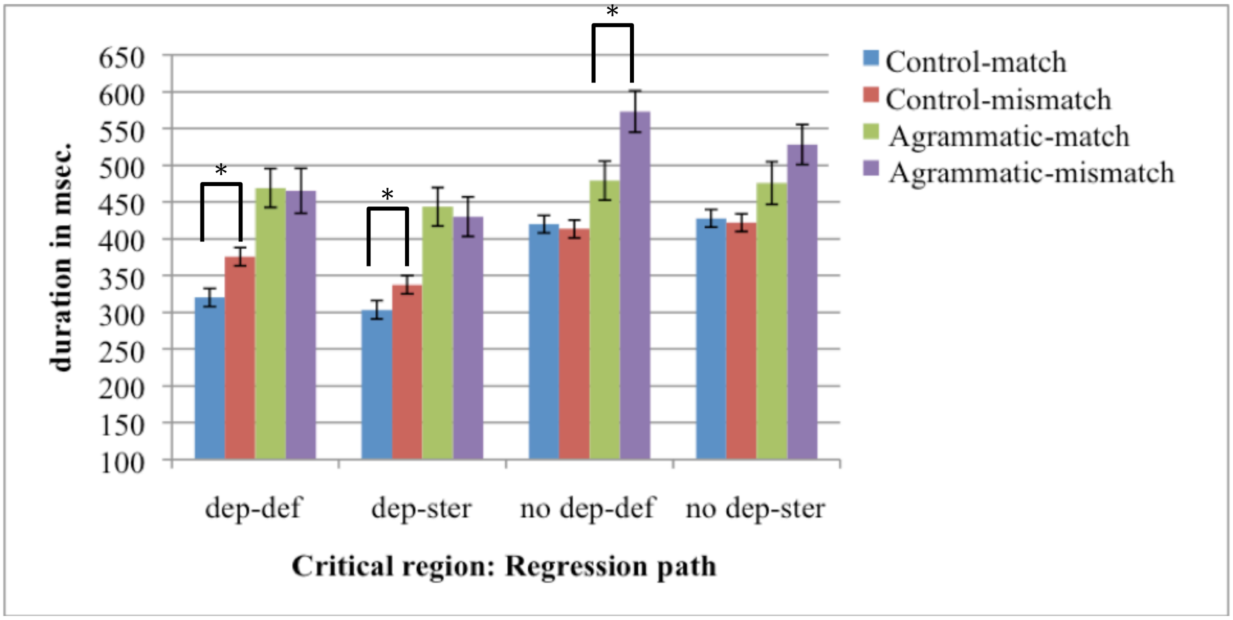

Figure 1 Regression path durations in the critical region. dep=dependency; no dep= no-dependency; def=definitional; ster=stereotypical. Within-group significant differences between match and mismatch conditions are indicated (*=p ≤ .05; #=p≤.10).

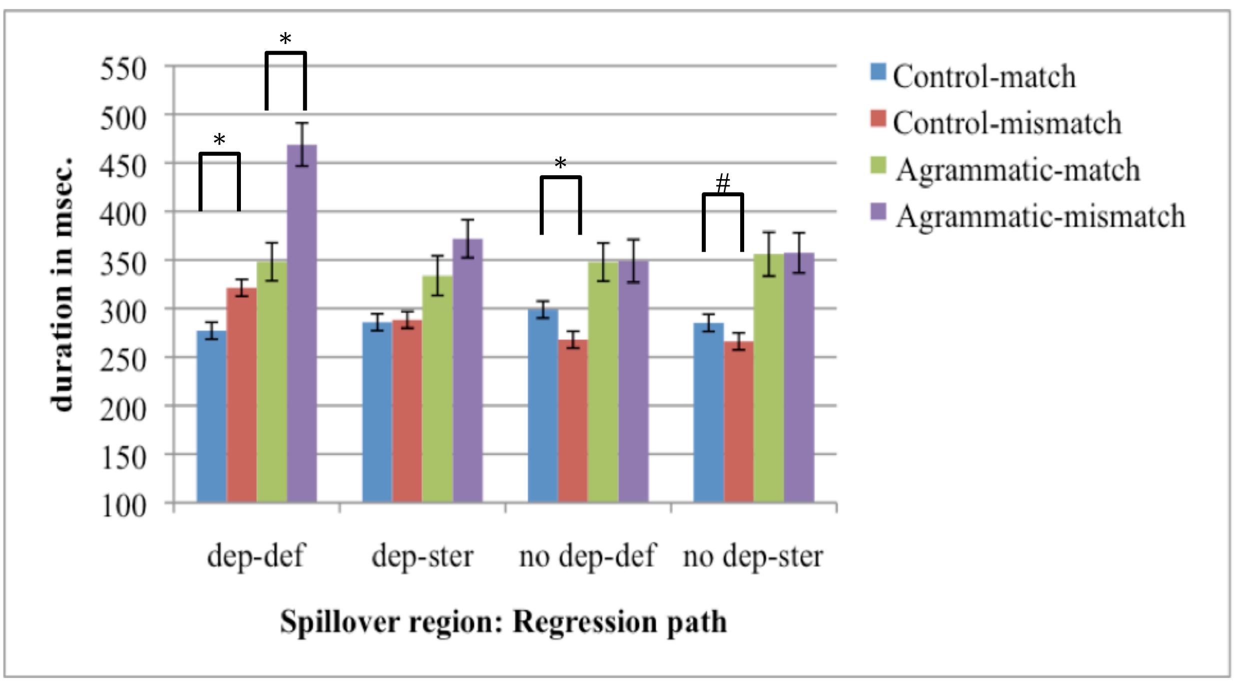

Figure 2 Regression path durations in the spillover region. dep=dependency; no dep= no-dependency; def=definitional; ster=stereotypical. Within-group significant differences between match and mismatch conditions are indicated (*=p ≤ .05; #=p≤.10).

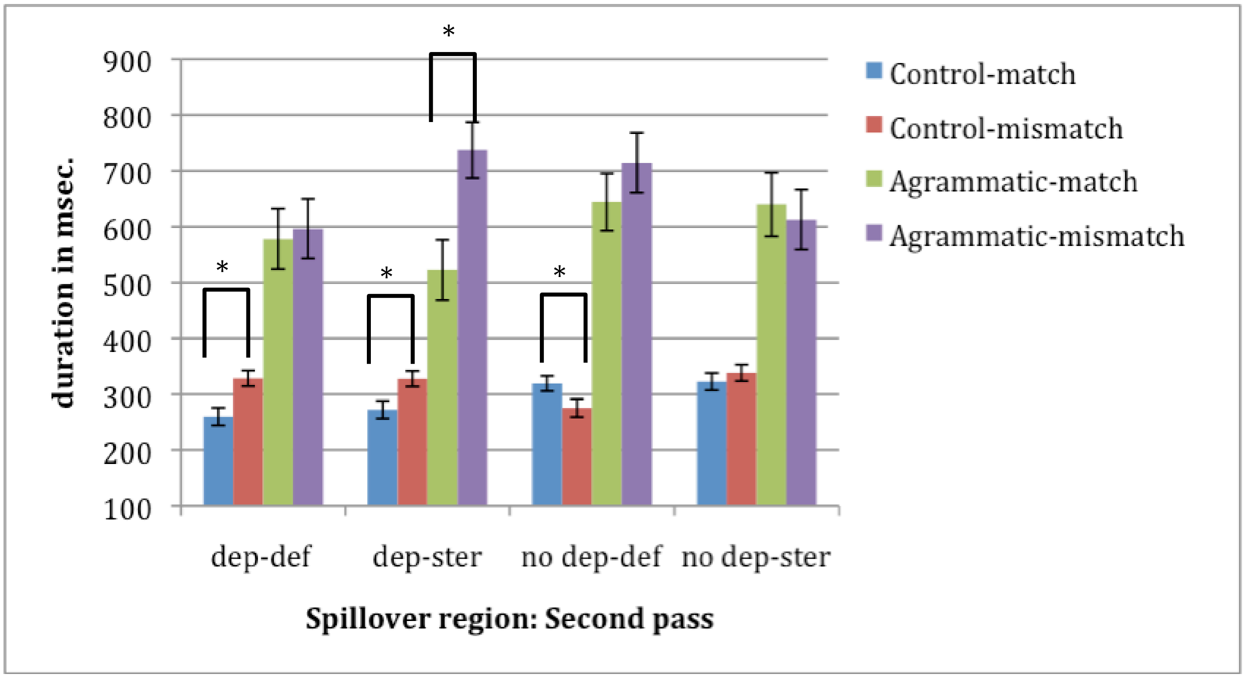

Figure 3 Second pass durations in the spillover region. dep=dependency; no dep= no-dependency; def=definitional; ster=stereotypical. Within-group significant differences between match and mismatch conditions are indicated (*=p ≤ .05; #=p≤.10).