

# Longitudinal Changes in Linguistic Complexity Among Professional Mixed Martial Artists

## Abstract

Typically, as one ages, their sophistication of speech increases due to an expansion in vocabulary depth. Various neurological disorders have the ability to impact one's linguistic complexity. The objective of this study is to analyze the trends in linguistic complexity in Mixed Martial Artists (MMA) who are at risk of developing the neurological disorder, Chronic Traumatic Encephalopathy (CTE). This disorder is thought to be caused by repetitive traumatic brain injury, therefore the risk of developing this disorder is increased in MMA fighters due to excessive exposure to blunt head trauma. Changes in Lexical Density over a 10-15 year period were measured by transcribed interviews of the MMA fighters and compared to transcribed interviews of the control. Subjects were placed into groups based on knockouts experienced throughout their career, 0, 1-3, 4-6, 7-9, and 10+, respectively. An analysis of variance (ANOVA) was performed to compare the slopes of data over a ten year span. There was no statistically significant difference between the groups with knockouts below ten. The ANOVA reveals that those who have had ten or more recorded knockouts experienced an overall decline in Lexical Density compared to those who have had 0 recorded knockouts. This trend persists even after controlling age and years participating in the sport as a potential confound. The results demonstrate that long term damage for fighters can impact their linguistic sophistication, which could be an indicator of CTE, therefore, steps should be taken to minimize the number of knockouts experienced over a career.

## Background

Mixed Martial Artists (MMA) are athletes who are exposed to mild to severe head trauma due to the punching and kicking that is the nature of their sport. Consistent traumatic brain injury (TBI) has been associated with the risk of developing Chronic Traumatic Encephalopathy (CTE). CTE is characterized as a neurodegenerative disease caused by abnormal buildup of tau protein in neurons and glial cells. CTE shares multiple symptoms with other neurodegenerative diseases, such as Alzheimer's disease. Due to this, diagnosis of CTE is only possible post mortem through evaluation of p-tau deposits in the brain (McKee 2009).

The symptoms of CTE vary, contributing to the difficulties of diagnosis. However, known symptoms are disruptions in mood and behavior, motor impairments, and cognitive decline (McKee 2009). Due to its undiagnosable nature, treatment is not able to be enacted. The differentiation of CTE and other tau buildup neurodegenerative diseases has been discovered, however, in order to analyze and differentiate, doctors must dissect the patient's brain and locate exactly where the abnormal tau buildup is (McKee 2009). CTE is extremely prevalent in athletes who take continuous blows to the head. In a study conducted by Anne McKee, it was found that out of 51 confirmed cases of CTE, 49 were athletes. 39 were boxers, 5 were football players, 1 professional wrestler and 1 soccer player (McKee et. al). Due to the compelling evidence from this study, many similar studies have been conducted. For example, Arizona State University's Visar Berisha conducted a study entitled "Longitudinal Changes in Linguistic Complexity Among Professional Football Players," in which an analysis of NFL players' Lexical Density and Diversity over time occurred, through the use of transcribed interviews. This study is conducted similarly.

The ability to speak and understand language is dependent on cognitive health. Because of the strenuous work one's brain must undergo to produce sentences, numerous studies have developed different ways to measure one's ability to produce language. One of the ways scientists can measure a subject's linguistic capabilities- and thus their neural capabilities- is through the measure of Lexical Density (LD). LD is a measure that compares the proportion of lexical words over total words. In this study, LD was measured by a LD calculator on the website, "Analyzemywriting.com". Every subject had at least one interview from each year of their career transcribed and analyzed for a calculation of their LD for that year. These data points were then placed on a graph which showed either a positive or negative linear slope. When these slopes were entered into "Vassarstats.net" and tested for ANOVAS, it was revealed that there is a statistically significant relationship between the number of knockouts a subject has experienced and their LD. The negative slopes proved concerning due to the fact that numerous studies have revealed that lexical ability should increase, or at least remain stable with age in neurologically healthy people (Susan 2001). Diversity and sophistication of language is supposed to increase with age (Kemper 2001). A decrease in lexical ability as these subjects age is indicative of a neurological issue that is hindering their linguistic abilities.

## Subjects

Fighter Identification #	Age of Entry to Fighting	Years Spent Fighting	Knockouts Sustained
1	21	11	0
2	24	12	2
3	21	10	1
4	25	11	5
5	22	11	5
6	23	11	4
7	24	15	3
8	21	15	4
9	21	15	11
10	21	15	15
11	20	11	5
12	21	15	7
13	24	15	4
14	20	14	2
15	23	10	2

**MMA Subjects**

## Hypothesis

A fighter with a larger number of knockouts in a 10-15 year period will demonstrate a greater decline in Lexical Density than one who experienced less knockouts in that same period.

## Data

Year	Control	Fighter #2	Fighter #3	Fighter #4	Fighter #5	Fighter #6	Fighter #7	Fighter #8	Fighter #9	Fighter #10	Fighter #11	Fighter #12	Fighter #13	Fighter #14	Fighter #15
1	41.26	39	42.3	39	40.4	43.4	42	39	42	39.9	41	43.2	43	37	43.5
2	44.98	42.8	40	39.6	39.2	41.3	42.3	41.3	41.5	40.3	42.4	45.6	43.5	38.9	42.3
3	43.97	41.9	43.4	42.9	40.5	44.5	44.3	40.5	40.2	40.8	42.7	43.6	42	40.33	39.4
4	47.88	42.9	45	44.4	41.2	43.7	41.4	42.3	41.2	41.6	44.6	42.5	40.33	39.89	40.8
5	42.5	43.5	42.3	43.4	39.9	44.1	45	40.9	43.4	39.5	43.9	39.99	42.4	40.99	42.3
6	47.53	41.2	40.55	42.8	42.3	43.2	43.2	41.2	43.5	41	40.1	43.6	43.4	41.3	43.4
7	42.99	39.5	42.7	43.7	43.5	45.3	42.4	43.4	43.9	43.9	45.6	45.4	43.9	40.3	43.8
8	45.6	44.6	43.4	42.8	43.8	44.5	43.6	42.2	44.5	45.6	45.8	42.4	44.5	42	44.2
9	53.35	46.3	44.5	44.6	43.1	45.6	44.6	40	42.3	42.4	40.33	43.5	46.7	42.9	44.9
10	37.22	43.4	41.3	45.2	43.6	43.4	43.4	40.1	41.4	42.6	43.56	40.3	47.55	41.2	45.4
11	49	49.5	44.3	40.7	43.4	43.6	42.4	41.5	40.3	43.2	42.89	43.87	48.5	41.9	46.5
12	52.715	43.4	44.9	42.5	42.3	46.2	45.7	42.5	40.6	40.6	41.4	45.9	46.8	40.3	45.9
13	49	45.2	45.5	45.2	44.4	47.4	44.9	43	40	39.5		44.7	47	39	46
14					43.5		45.5		39.2	38.95		46		40.4	46
15					44.4				39.4	38.6					46.5

**Lexical Densities of Fighters #1-15 Over the Duration of Their Career**

### Data Summary

	Samples					Total
	Control	M1	M2	M3	M4	
N	1	5	5	1	2	14
Σ X	0.511	1.439	1.4044	0.121	-0.2332	3.2322
Mean	0.511	0.2878	0.28088	0.121	-0.1166	0.231586
Σ X <sup>2</sup>	0.261121	0.483817	0.532911	0.014641	0.03523	1.32772
Variance	NaN	0.017418	0.034611	NaN	0.008039	0.044375
Std. Dev	NaN	0.131978	0.18604	NaN	0.089661	0.210653
Std. Err	NaN	0.059022	0.083199	NaN	0.0634	0.056299

# Procedure

1. Identify 16 Mixed Martial Artists who will be used in the study. All Martial Artists must fall in the following criteria:
  - a. Must be fluent in English
  - b. Must have started professional career between 21-26 (age at first interview)
  - c. Must have a career of at least 10 years
  - d. Must have spoken at least 5,000 words in interviews (word window of 5,000-7,500 words).1b. Identify 1 Martial Artist who falls in the following criteria:
  - a. Must be fluent in English
  - b. Must have started professional career between 21-26 (age at first interview)
  - c. Must have spoken at least 5,000 words in interviews
  - d. Must have never experienced a knockout
1. Assign numerical values to each Martial Artist and coach to ensure anonymity- house information in a private computer where only the scientist has access.
2. Group participants by number of knockouts sustained (0), (1-3), (4-6), (7-9), (10-12) using Sherdog.com to gather this information.
3. Obtain interviews for each fighter where they speak at least 100 words via their fighting agency and/or various MMA Podcasts.
4. Transcribe interviews for each fighter into a word processing document.
5. Paste transcription into [analyzemywriting.com](http://analyzemywriting.com) for the lexical density ratio
6. Group data by number of knockouts
7. Graph data on a linear regression scatterplot using VassarStats.net
8. Calculate ANOVA's comparing the control group to fighters with (1-3), (4-6), (7-9), and (10-12) knockouts using VassarStats.net
9. Evaluate data to determine if a statistically significant difference exists between the groups prior to boxing and at the end of the ten year interval and draw conclusions
10. Write conclusion

# Results

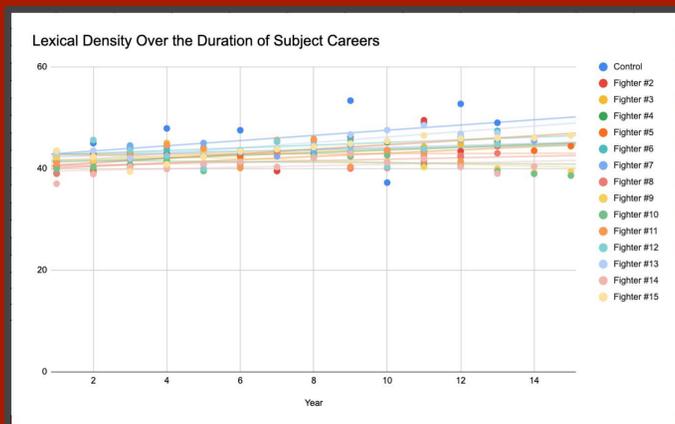
Below are the ANOVA results, along with a key.

Key:
Control = Mean LD of Fighters who have sustained 0 knockouts
M1 = Mean LD of Fighters who have sustained 1-3 knockouts
M2 = Mean LD of Fighters who have sustained 4-6 knockouts
M3 = Mean LD of Fighters who have sustained 7-9 knockouts
M4 = Mean LD of Fighters who have sustained 10+ knockouts

Groups Compared	P-Value
Control:M1	Insignificant
Control:M2	Insignificant
Control:M3	Insignificant
Control:M4	P < 0.5
M1:M2	Insignificant
M1:M3	Insignificant
M1:M4	Insignificant
M2:M3	Insignificant
M2:M4	Insignificant
M3:M4	Insignificant

As previously mentioned, it was discovered that fighters with knockouts 0-9 did not have any data supporting that they had a significant decline in LD. However, when an ANOVA was performed on the control group and the M4 group (group with 10+ knockouts), the calculated p-value was less than 0.05, indicating there is statistical significance between the amount of knockouts a fighter undergoes, and their linguistic capabilities.

# Graph



# Limitations

This study used numerous controls to ensure the validity of the results. These controls include the following: English as their first language, must have started a career between twenty-one and twenty-six, must have a career length of at least ten years, and must have spoken at least 5,000 words in interviews throughout their entire career. Due to these controls, all subjects should have been in a relatively similar LD ranking based on their age. Also, the control on career length allows for an expectation of similar positive LD growth throughout each subject's career, because as one ages, their LD is expected to increase. However, for these subjects that ultimately was not the case. Despite the remarkability of these findings, there are numerous limitations placed upon this study due to the retrospective nature of the data. One limitation placed on this study was the sample size. Due to the restrictive criteria placed on each subject, the number of fighters who fit these guidelines was limited. Therefore, the sample size of 15 may not be representative of all 689 professional MMA fighters currently in the UFC. Also, due to the structure of this study, all that was used to calculate the LD of each fighter was a transcribed interview from that year. It should be noted that one singular interview may not be representative of that person's LD, however, due to limited access to other types of data- which would be more interviews or other videos of each fighter talking, there is a limitation on the accuracy of the estimation of each fighters LD throughout their career.

# Conclusion

The purpose of this experiment was to test the longitudinal changes in linguistic capabilities in MMA fighters over the course of their career. This longitudinal study utilized transcribed interviews of multiple MMA fighters throughout their career to calculate their Lexical Density. As their careers progressed, some fighters had experienced a decrease in LD, leading to the conclusion that multiple occurrences of TBI over the span of ten to fifteen years could lead to a decline in cognitive function. This confirmed the experiment's hypothesis. Despite the limitations of this study, it is undeniable that the results are astonishing. As previously stated, as one ages their Lexical Density is expected to increase. When analyzing the results of these athletes we see a distinct decrease in the LD overtime. This is extremely abnormal. A decrease in Linguistic abilities is correlated with a decrease in neural function (McKee 2009). This indicates that the fighters who had a decrease in their LD could have suffered enough TBI through their knockouts to have a detrimental effect on their cognitive function. Due to a loss of lexical ability being a harbinger of CTE (Berisha 2017), these injuries need to be taken seriously as they could lead to the development of this disease. When the group with more than ten knockouts was compared to the control group with zero knockouts, the calculated p value was less than 0.05, indicating statistically significant data. Furthermore, this means that those who have had more than ten knockouts over a ten to fifteen year span have had a decrease in LD that can be correlated with the amount of knockouts they have experienced. With the use of this data, scientists could determine that after 10 severe TBIs, an athlete should take recuperative measures to ensure they will not undergo any other head trauma. Doctors could also begin neurodegenerative treatment with these athletes to delay the onset and severity of CTE symptoms.

# Current Research

Recently, a study has been published that establishes the consensus among doctors to diagnose CTE among living patients. This research is a critical step in the right direction, as now doctors will be able to diagnose and begin treatment while patients are still living (McKee 2021). Without a specific criteria, many athletes suffered from CTE without knowing, and the effects were detrimental to their lives. For instance, Aaron Hernandez, an NFL player who killed Odin Lloyd, suffered from one of the most severe cases of CTE ever found by doctors. The severity of his CTE most certainly contributed to his actions. The development of a standard for CTE will help with furthering research by utilizing living subjects (McKee 2021) and save thousands of lives in the process.

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