New Interfaces for
Musical Expression

May 28, 2013 | Daejeon, Korea Republic

NIME 2013 KAIST

Adaptive mapping for improved pitch accuracy on touch user interfaces

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Outline

* Our instrument:
  The Cantor Digitalis
* Discrete and
  continuous mapping
* Adaptive mapping
* Experiment
* Conclusions

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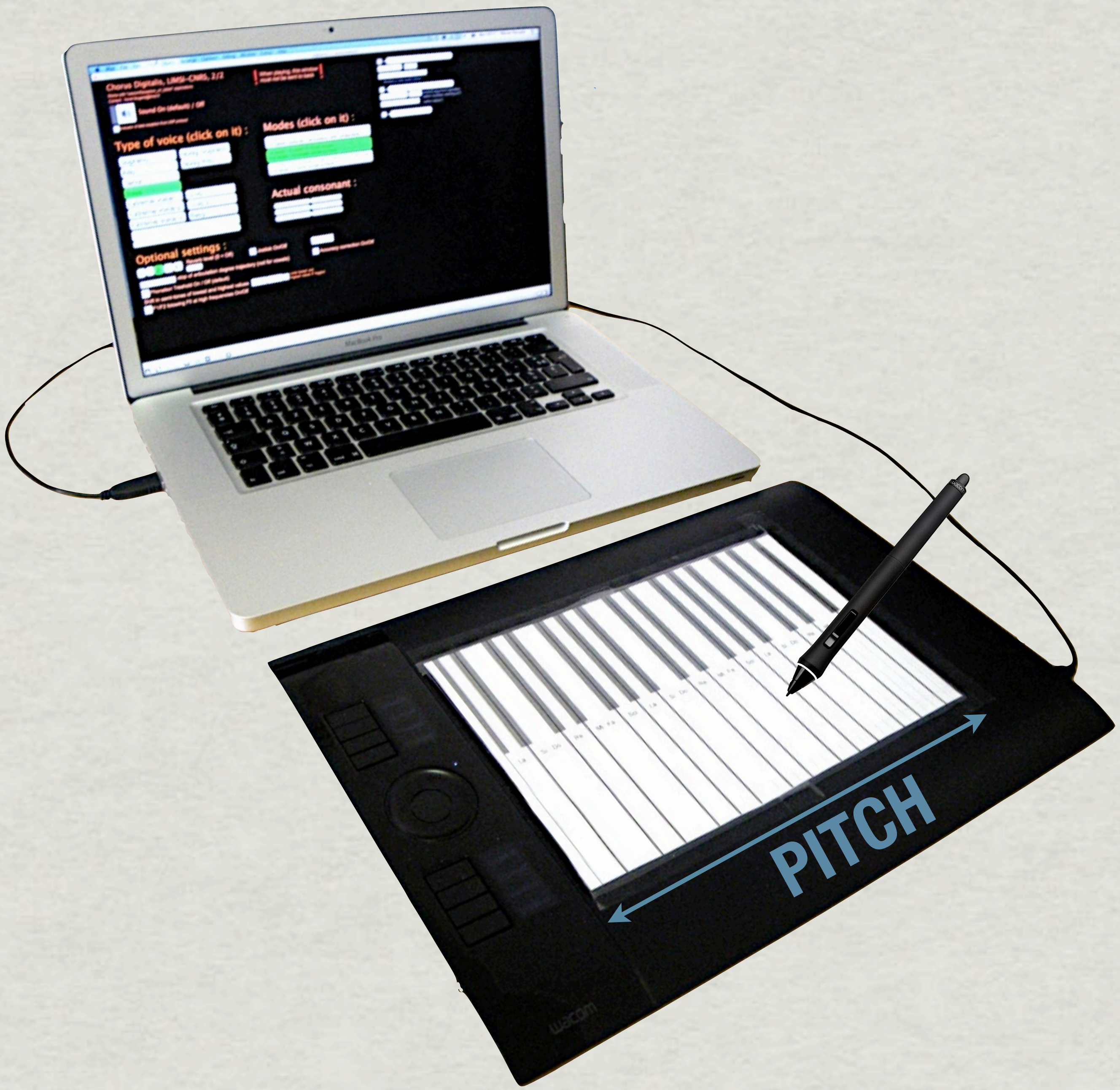
Cantor Digitalis

- Digital singing instrument
- Vocal synthesizer
  - Source + filter model
  - Real time
- Controlled by a graphic tablet
  - Vocal effort: stylus pressure
  - Pitch: stylus X-coordinate



Two constrains

- Vocal expressivity
  - Portamento
  - Vibrato
  - Glissando
  - Melodic ornaments
- Accuracy
  - Pitch controlled by an object position

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WHERE DO I PUT THE STYLUS / MY FINGERS TO PLAY IN TUNE ?

- Musician: *"You need at least 10 years of practice"*
- Scientist: *"It depends on the mapping between stylus position and pitch"*

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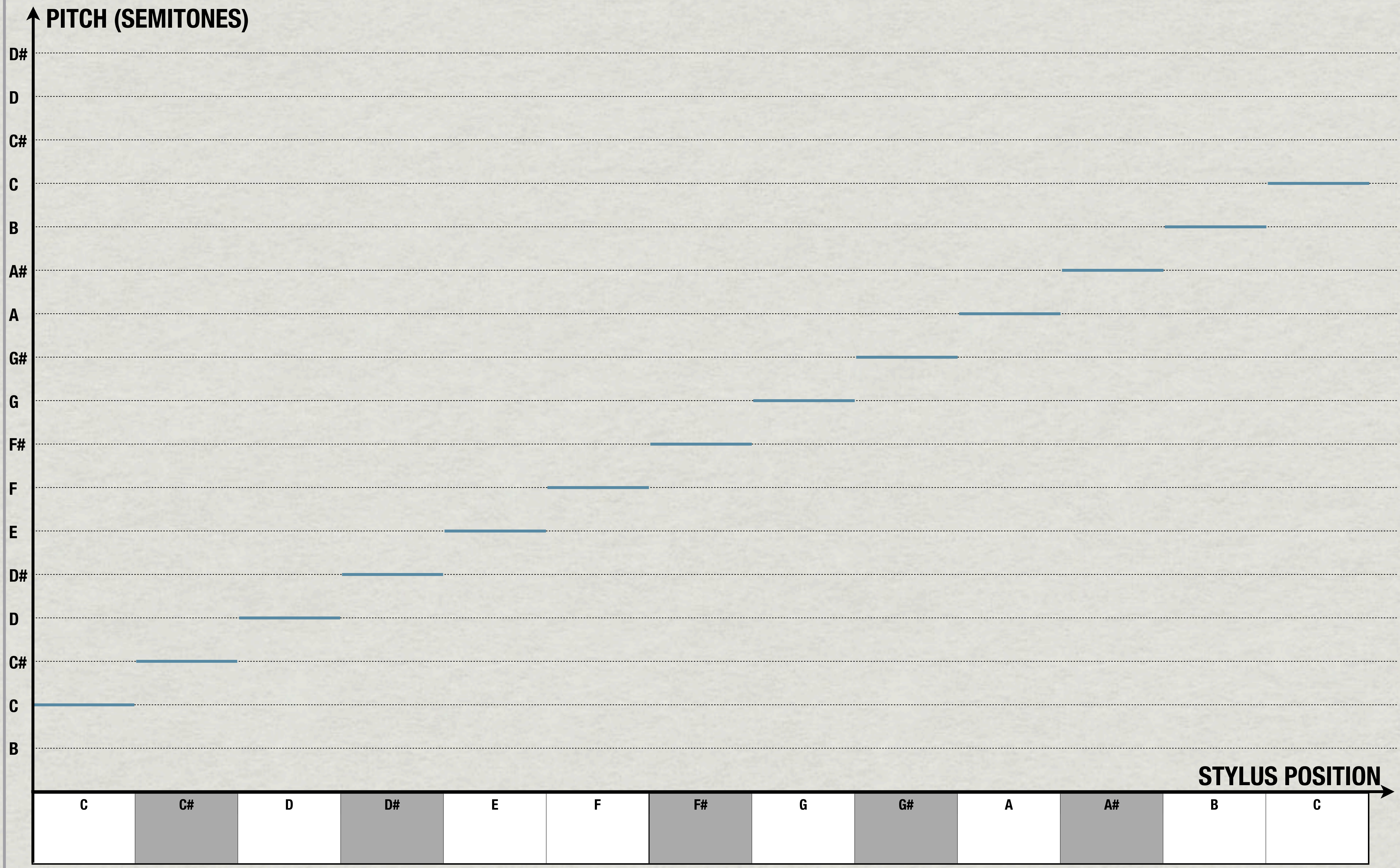
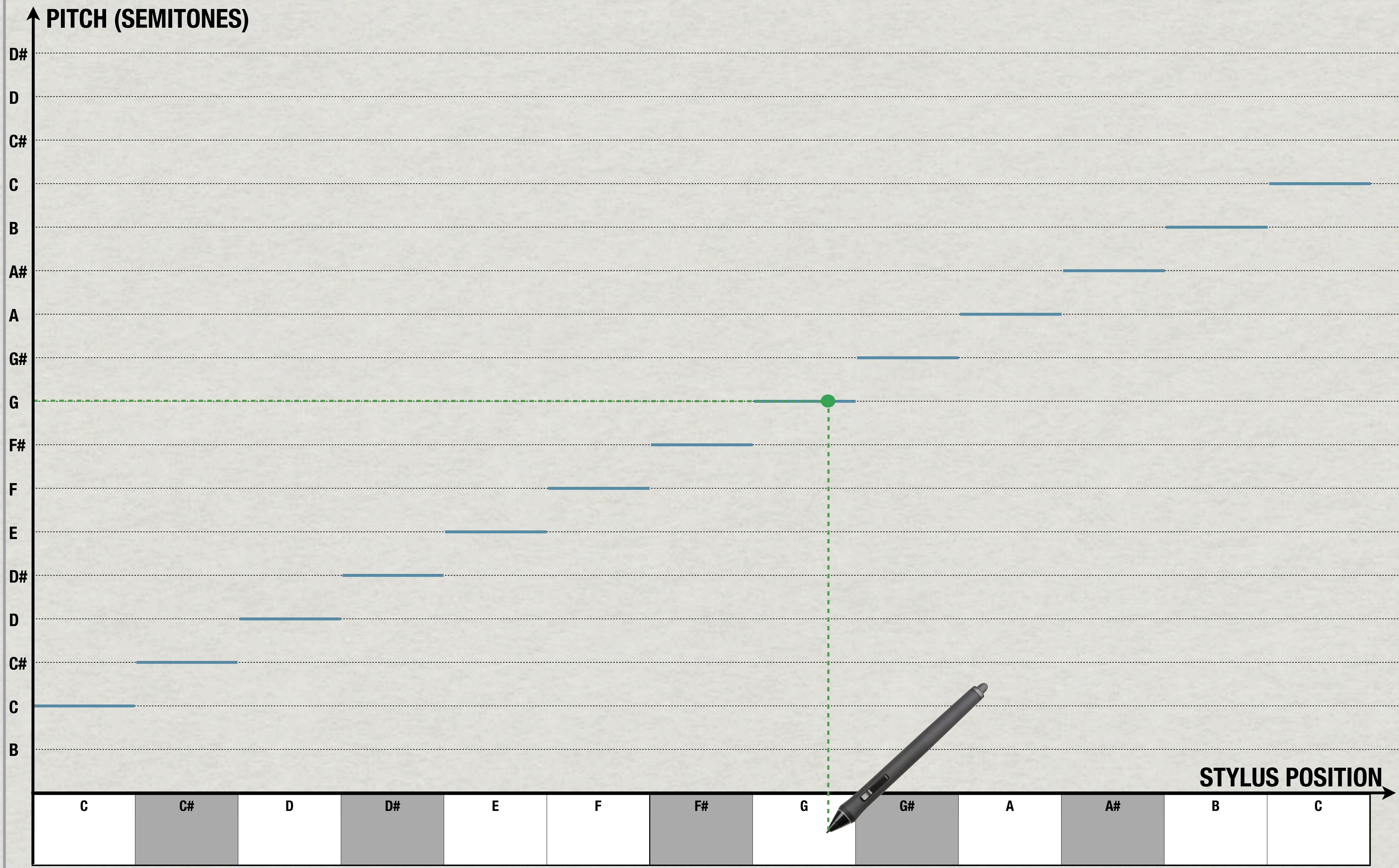
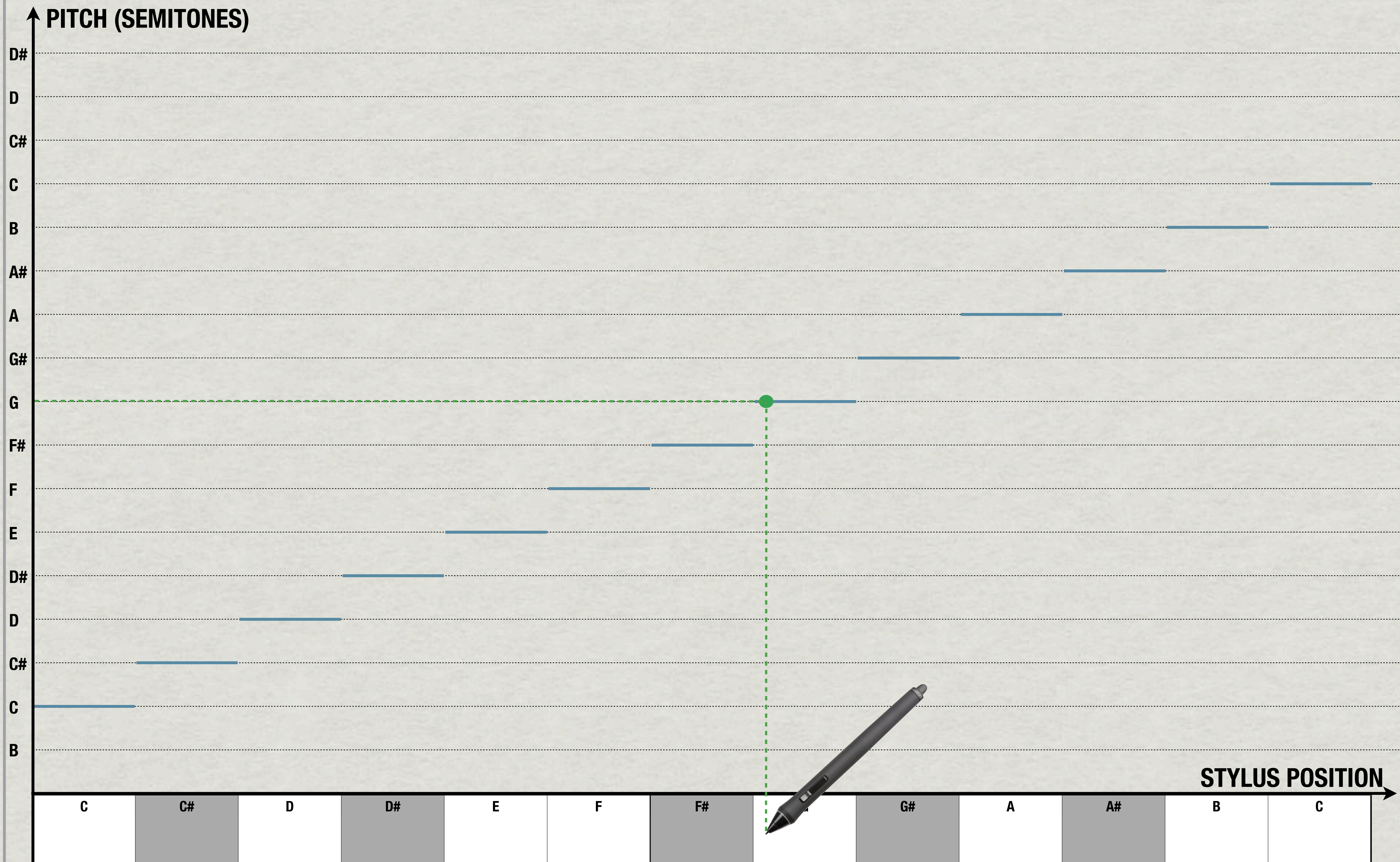
Discrete mapping



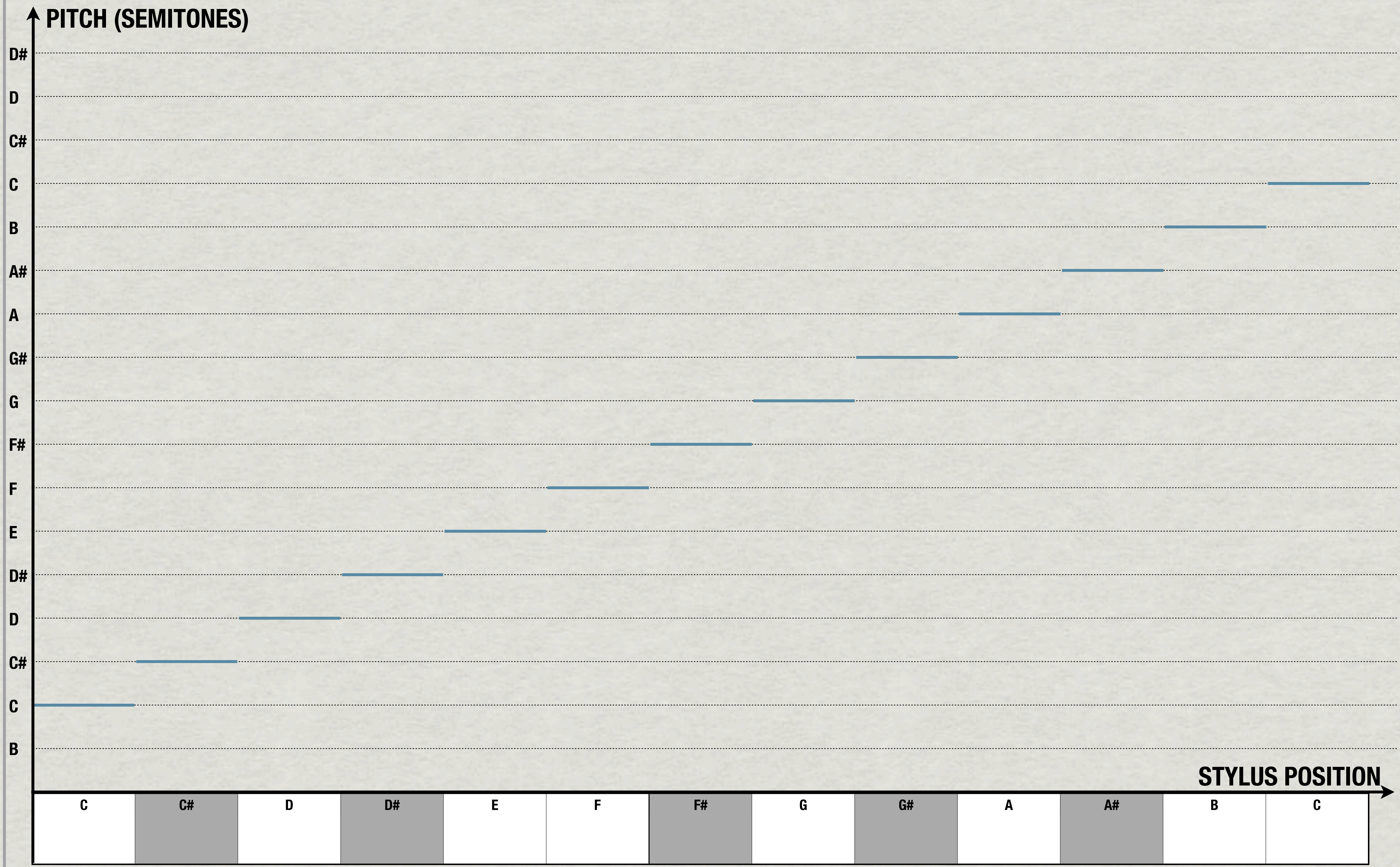
Discrete mapping



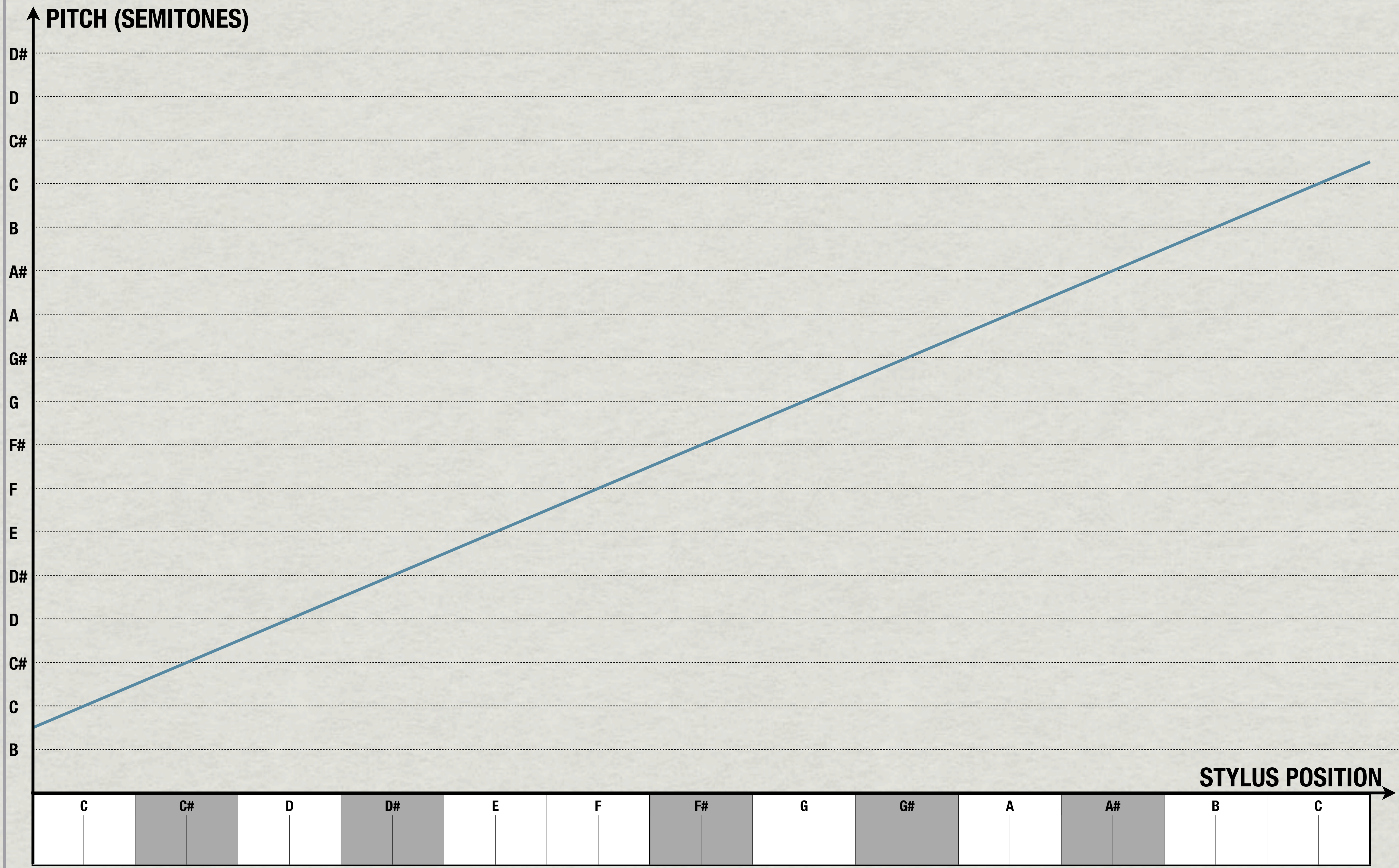
Discrete mapping



Discrete mapping



Continuous mapping



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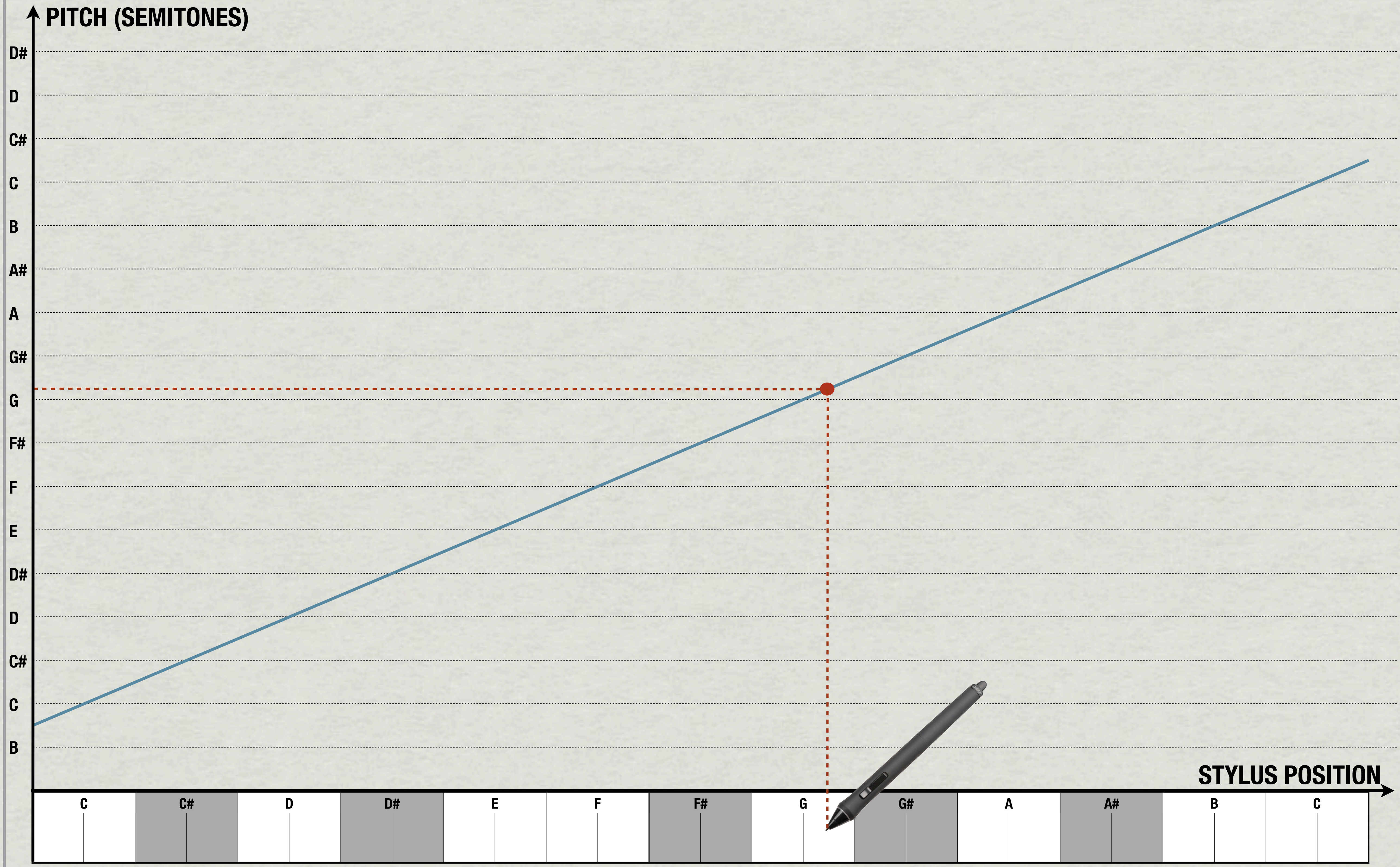

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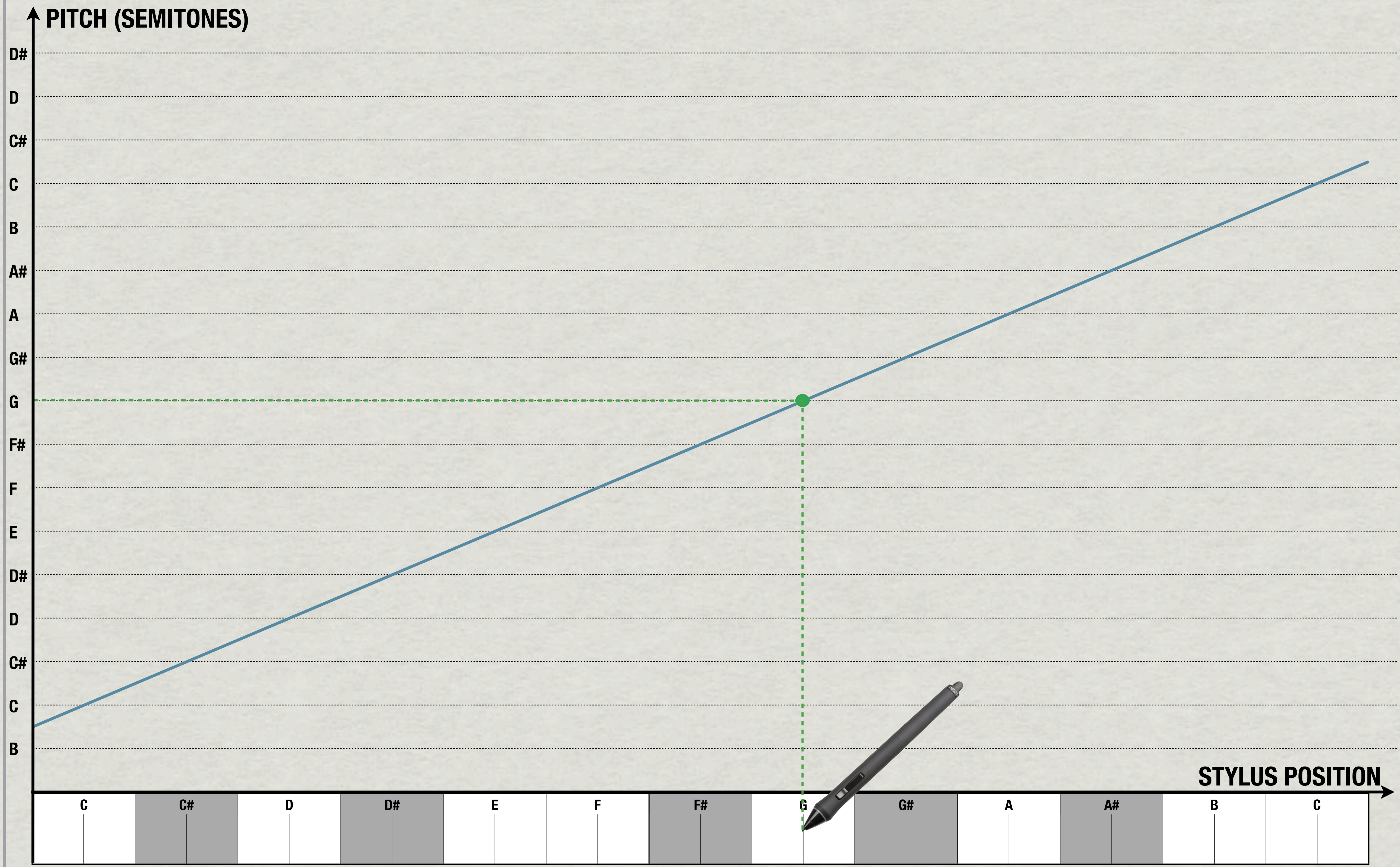

Discrete vs Continuous

	Discrete	Continuous
Accuracy	Inherent	Hard
Pitch expressivity	Low	High

- Improve expressivity in discrete mappings
- Improve accuracy in continuous mappings

Discrete vs Continuous

	Discrete	Continuous
Accuracy	Inherent	Hard
Pitch expressivity	Low	High

- Improve expressivity in discrete mappings
- Improve accuracy in continuous mappings

ADAPTIVE MAPPING

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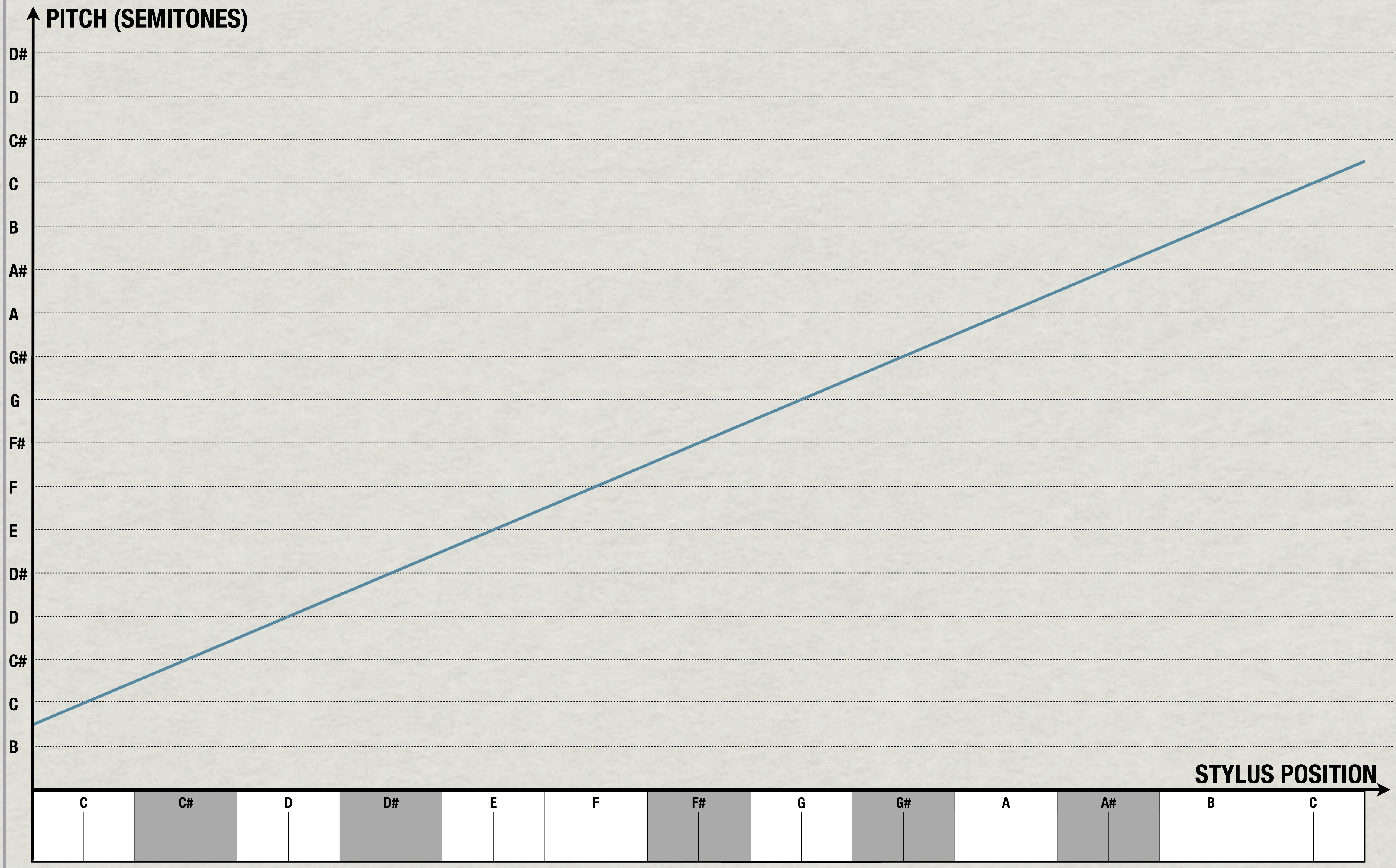

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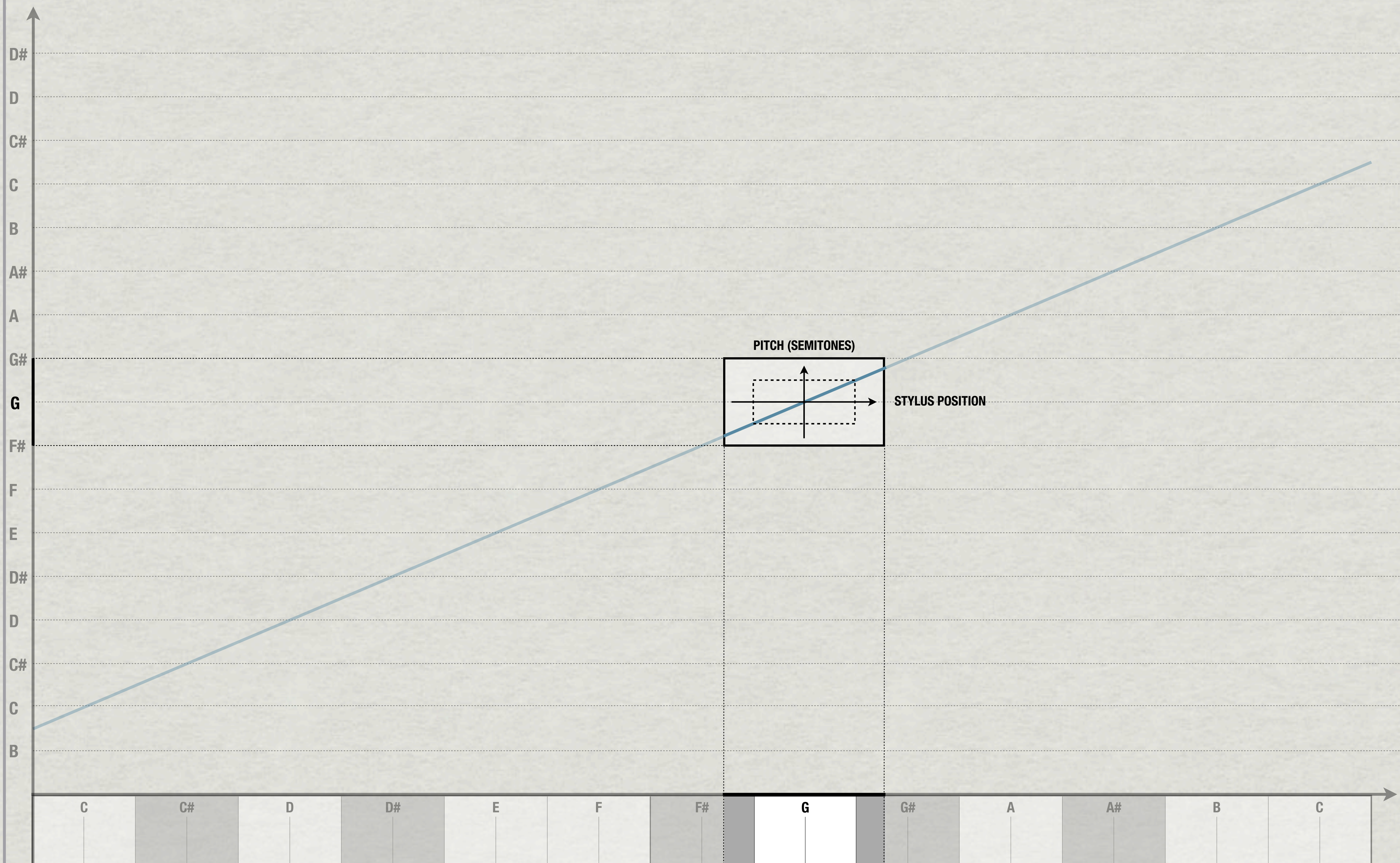
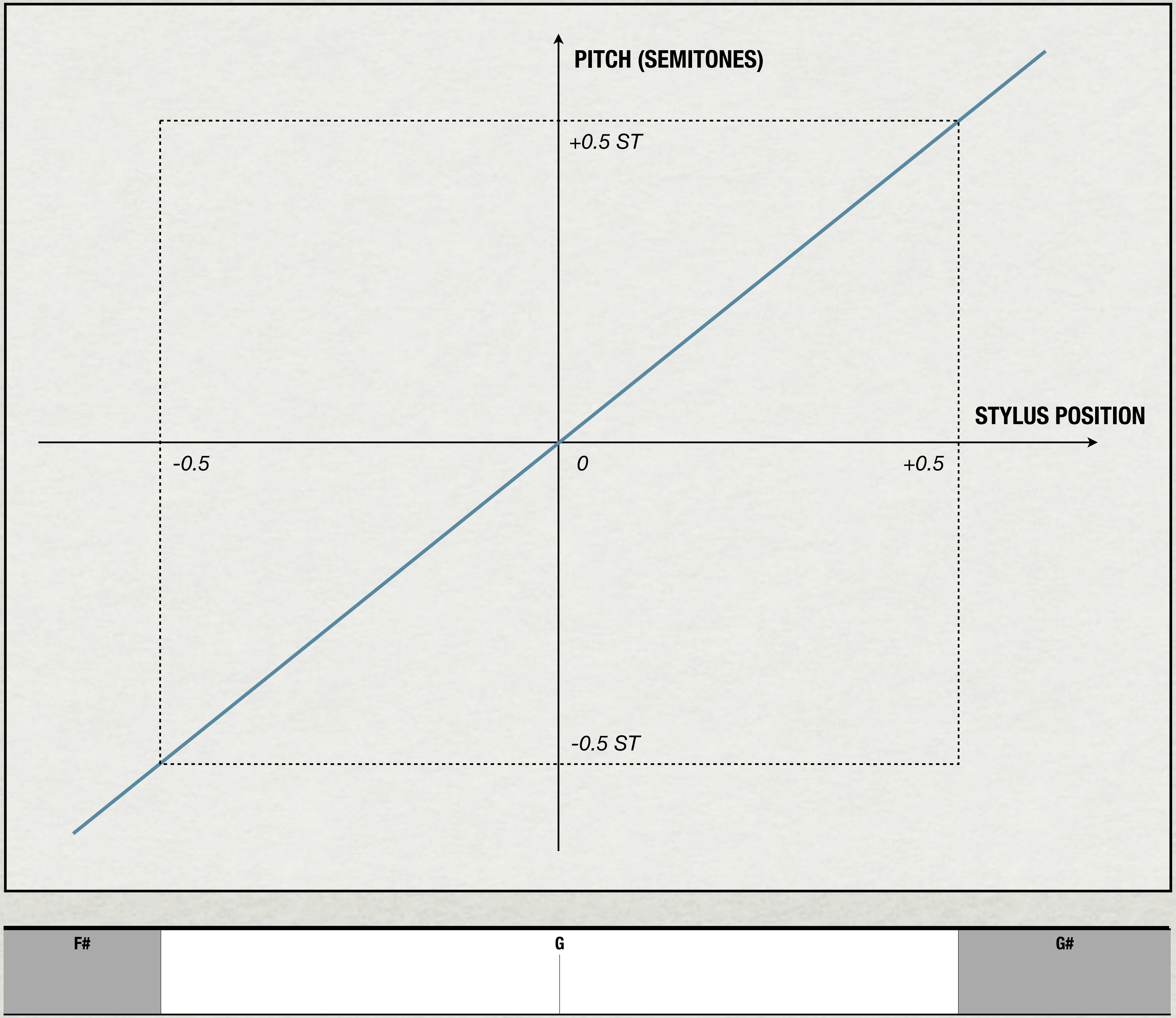
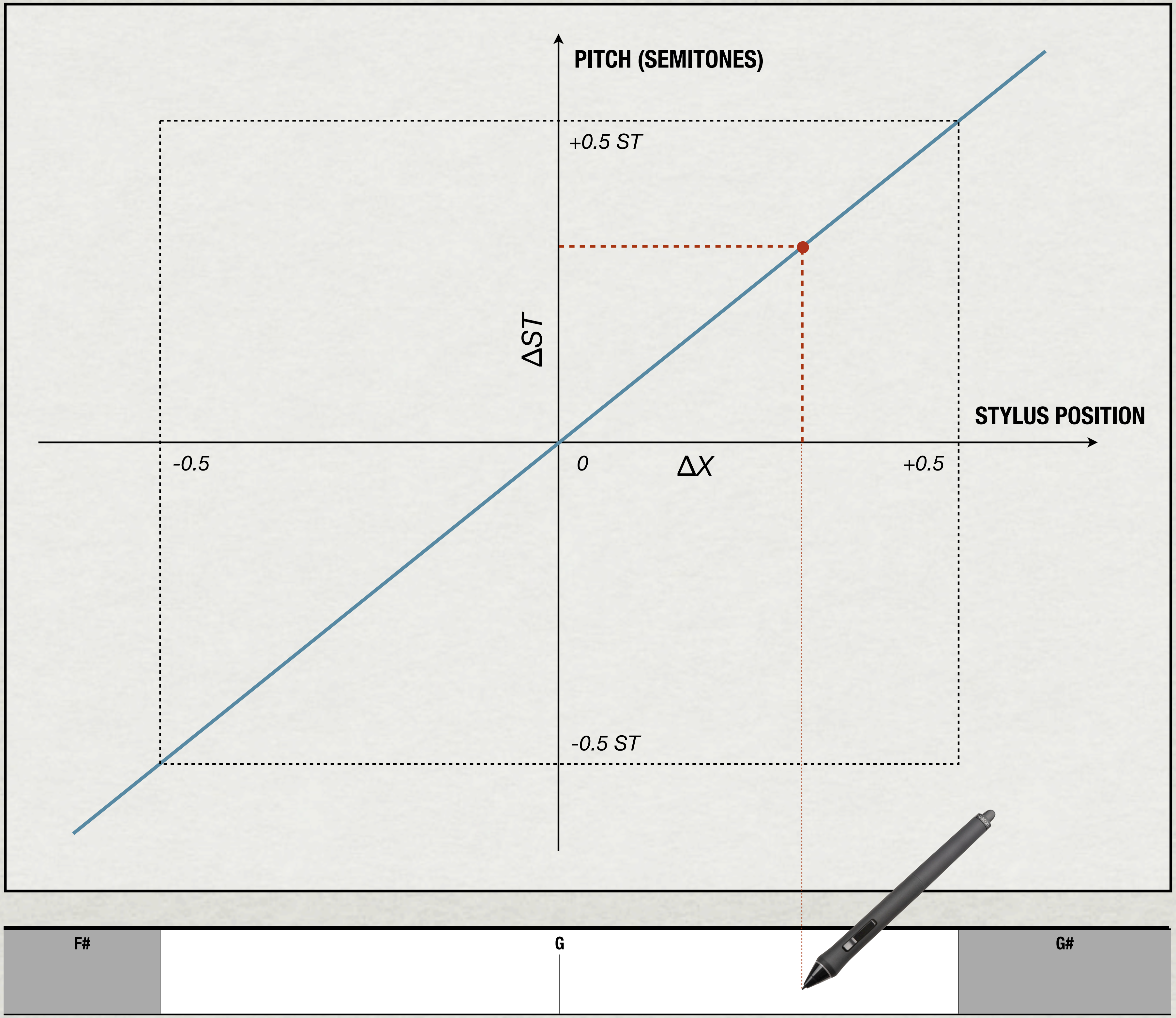


Linear mapping



- Proportional error between pitch and position
- Accurate pitch at precise position

Linear mapping



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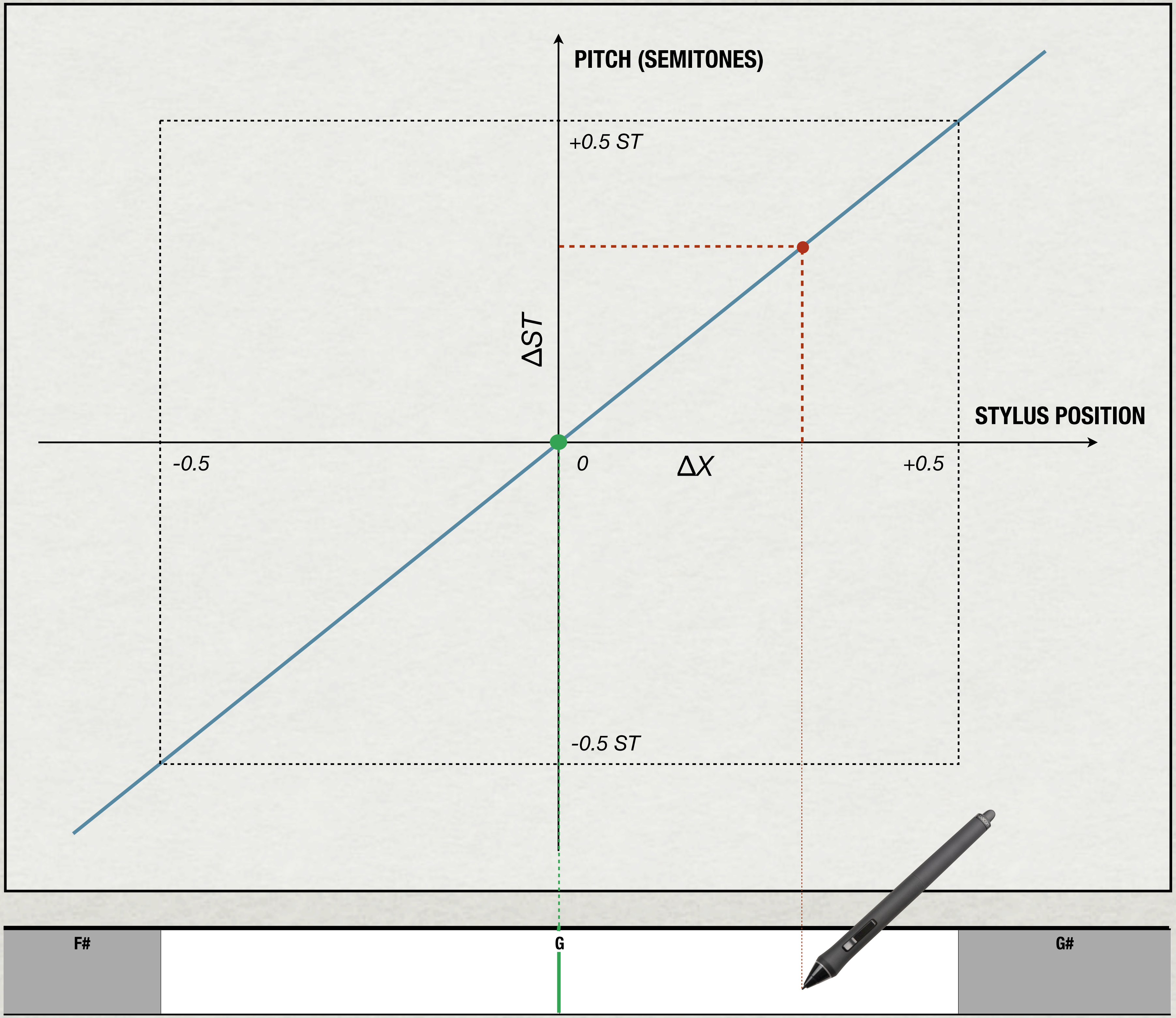

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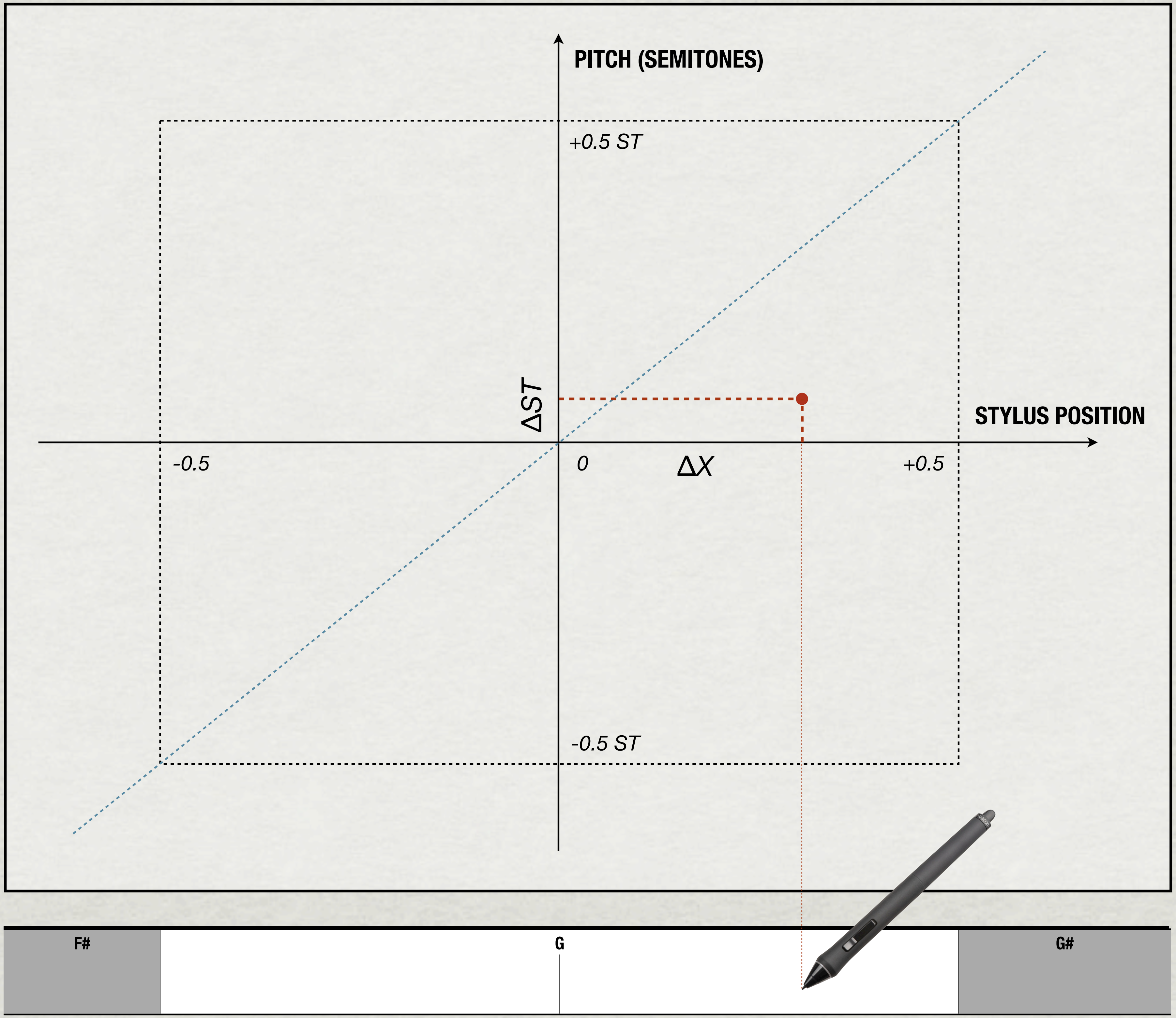
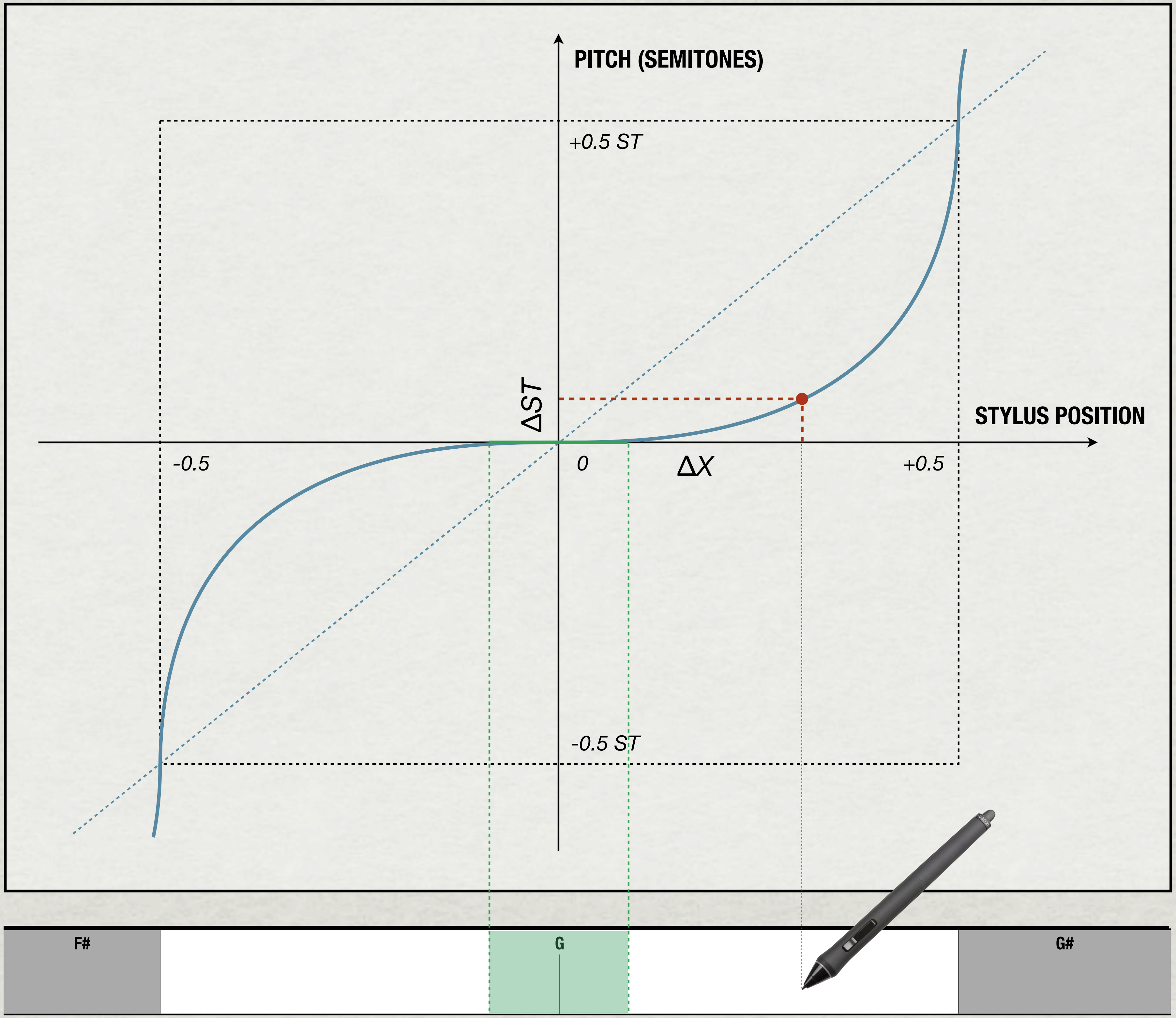
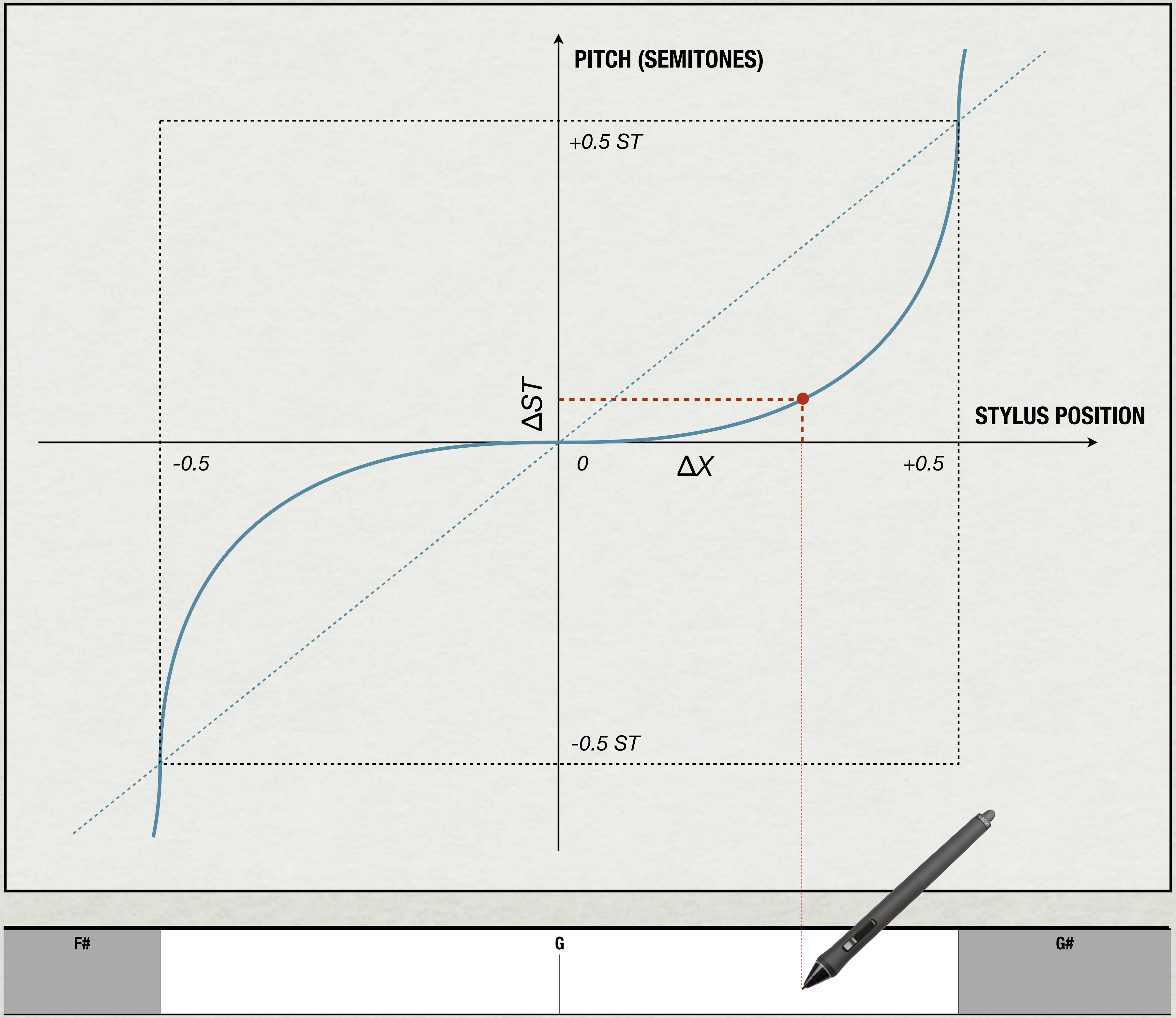


Non-linear mapping



- Contraction of curve around target
- Smaller error
- Larger range to play accurately
- Loss of expressivity

Non-linear mapping



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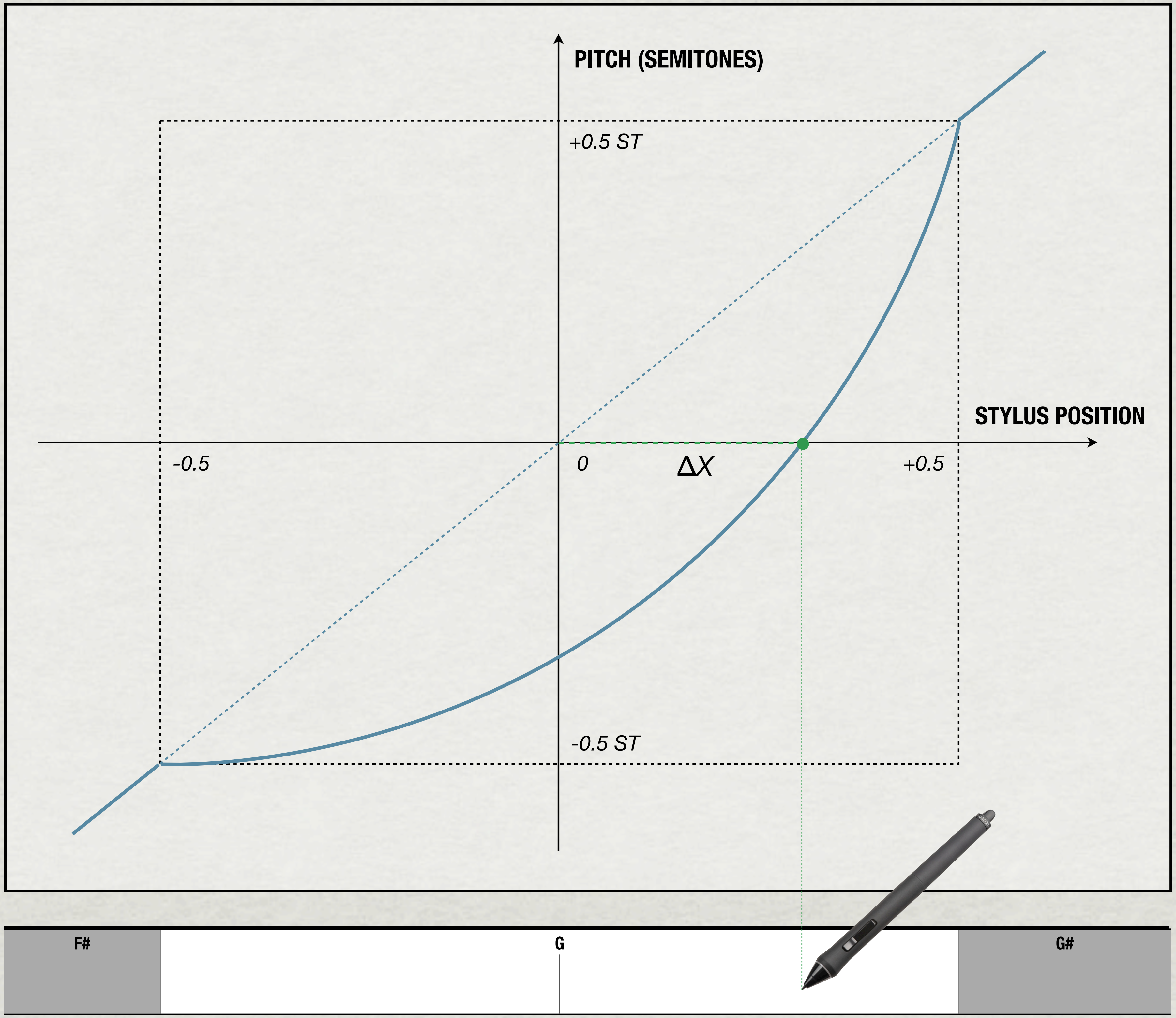
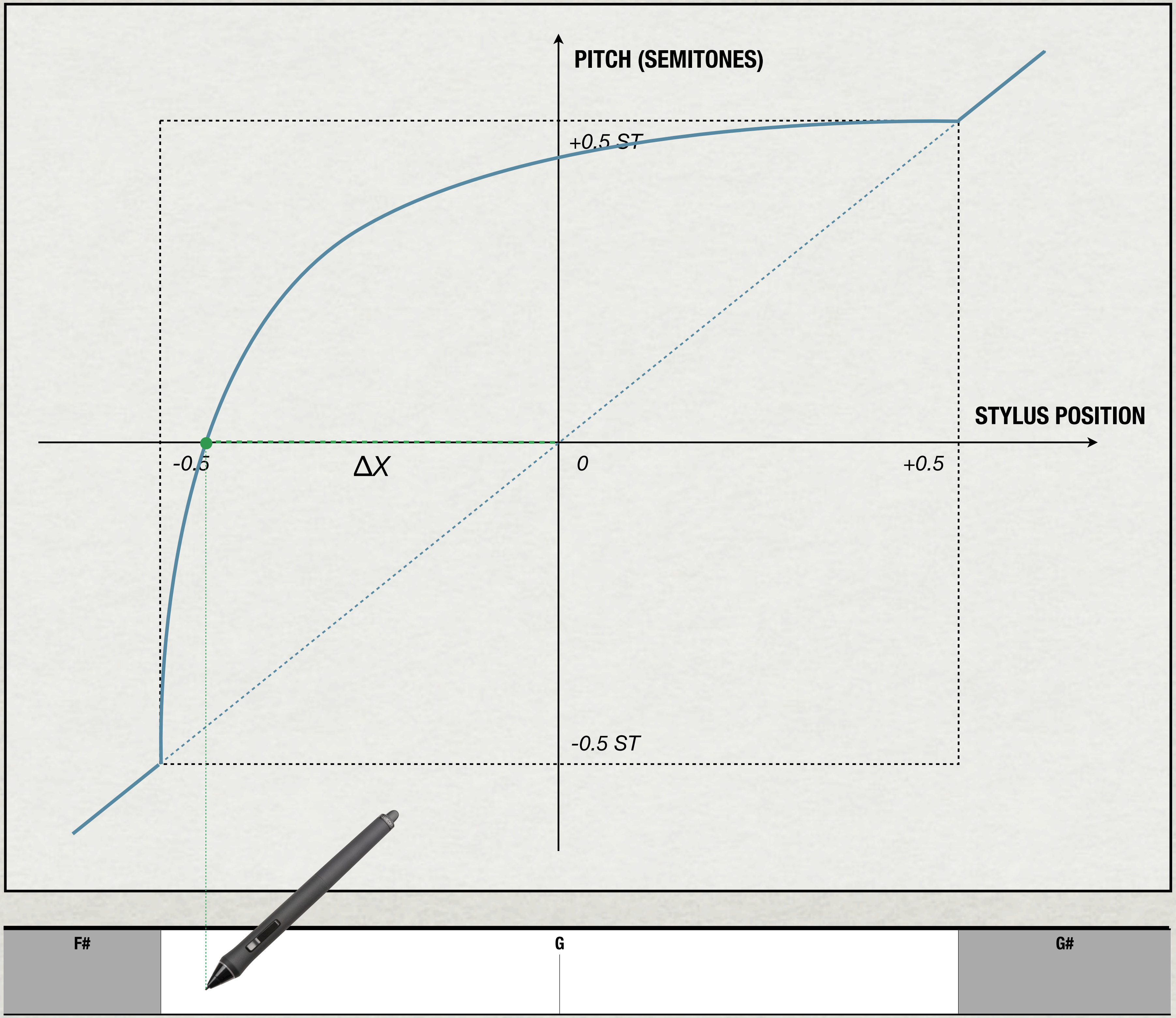


- Curve goes through the position of stylus
- Adaptation of the target
- Always play accurately

ONLY AT THE STYLUS CONTACT

- Keep expressivity after contact

Non-linear mapping



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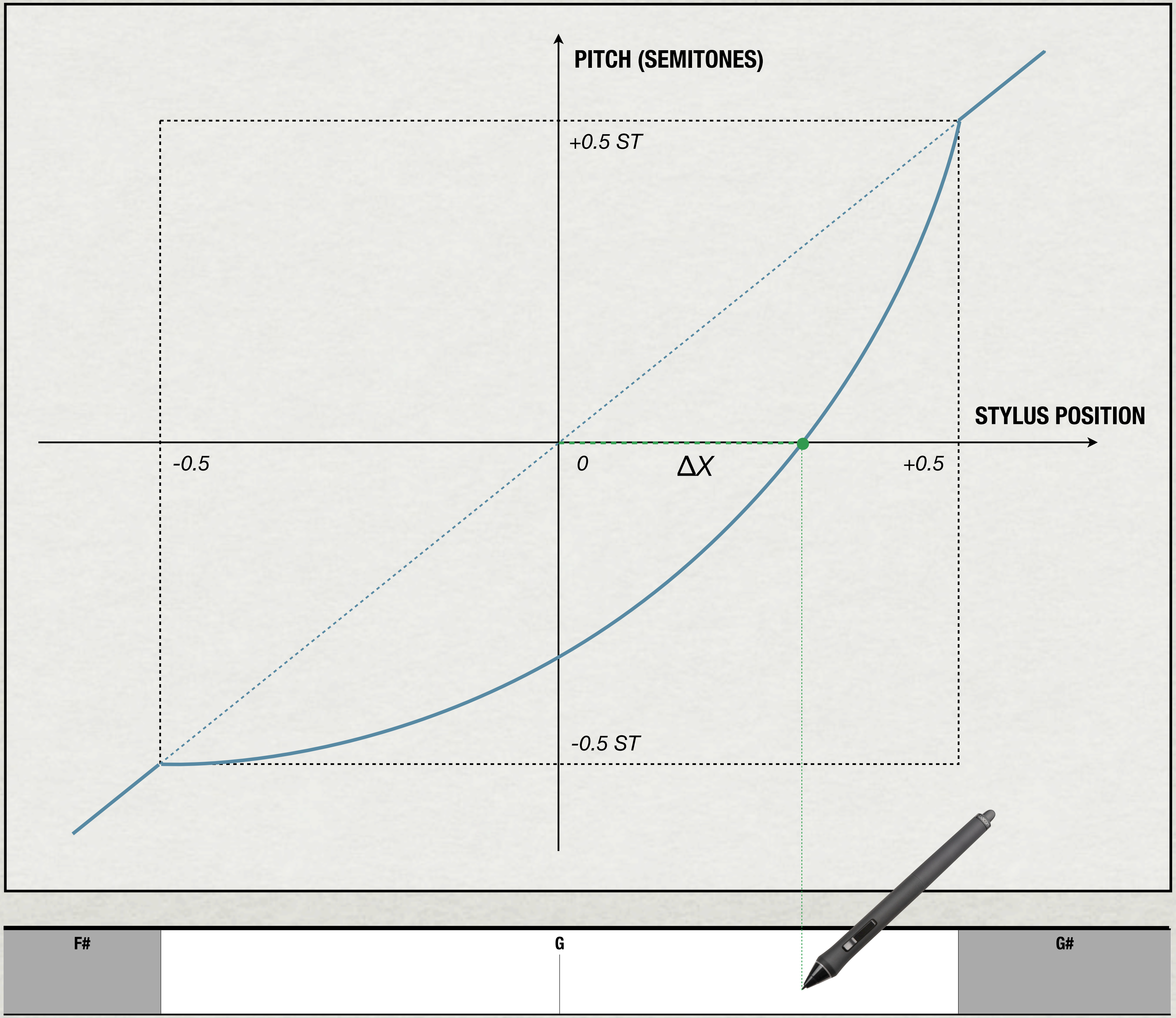

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ONLY AT THE STYLUS CONTACT

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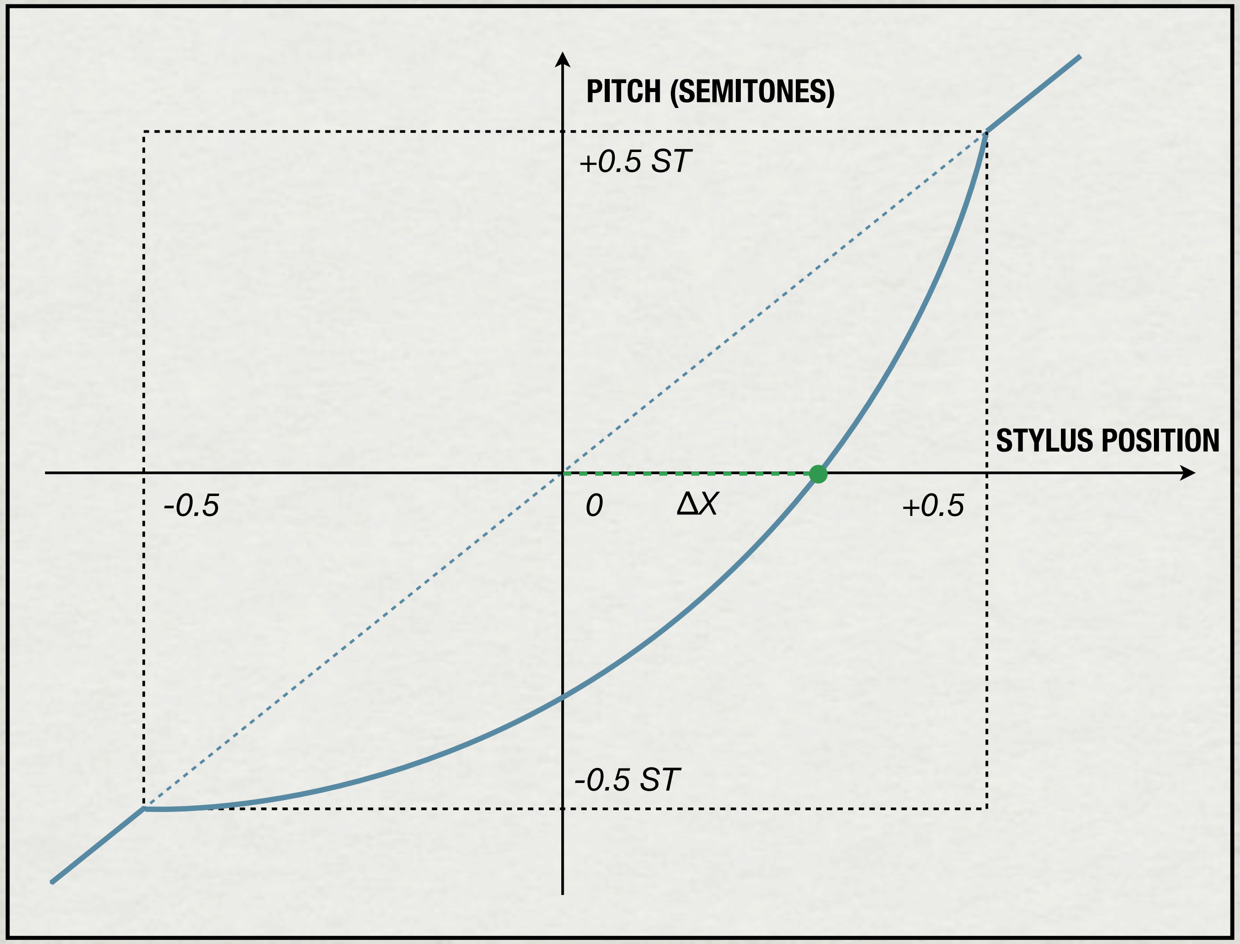
Analytic expressions

- Two conditions
  - Value at contact is 0
  - Continuity at (-0.5 ; -0.5) and (+0.5 ; +0.5)

→ $$g(y) = \frac{e^{(y+0.5)\gamma} - 1}{e^{\gamma} - 1} - 0.5$$ ↔ $$y = f(x) = \frac{1}{\gamma}\left[\log\left[(e^{\gamma} - 1)(x + 0.5) + 1\right]\right] - 0.5$$

x = pen position
y = pitch
γ = curvature

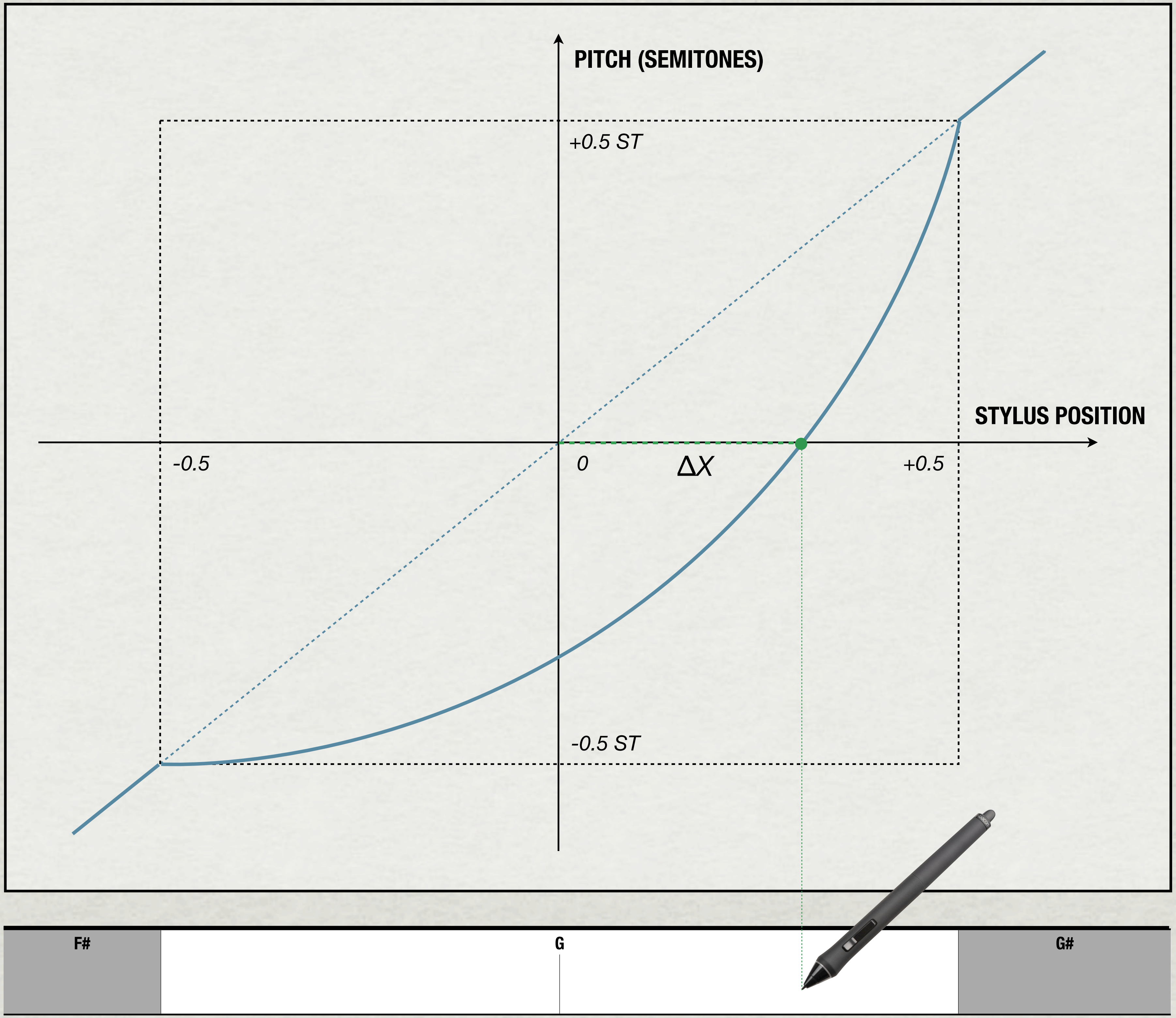


- Curvature
  - Computed at each contact

→ $$\gamma_0 = 2\log\left(\frac{1 - 2x_0}{1 + 2x_0}\right)$$

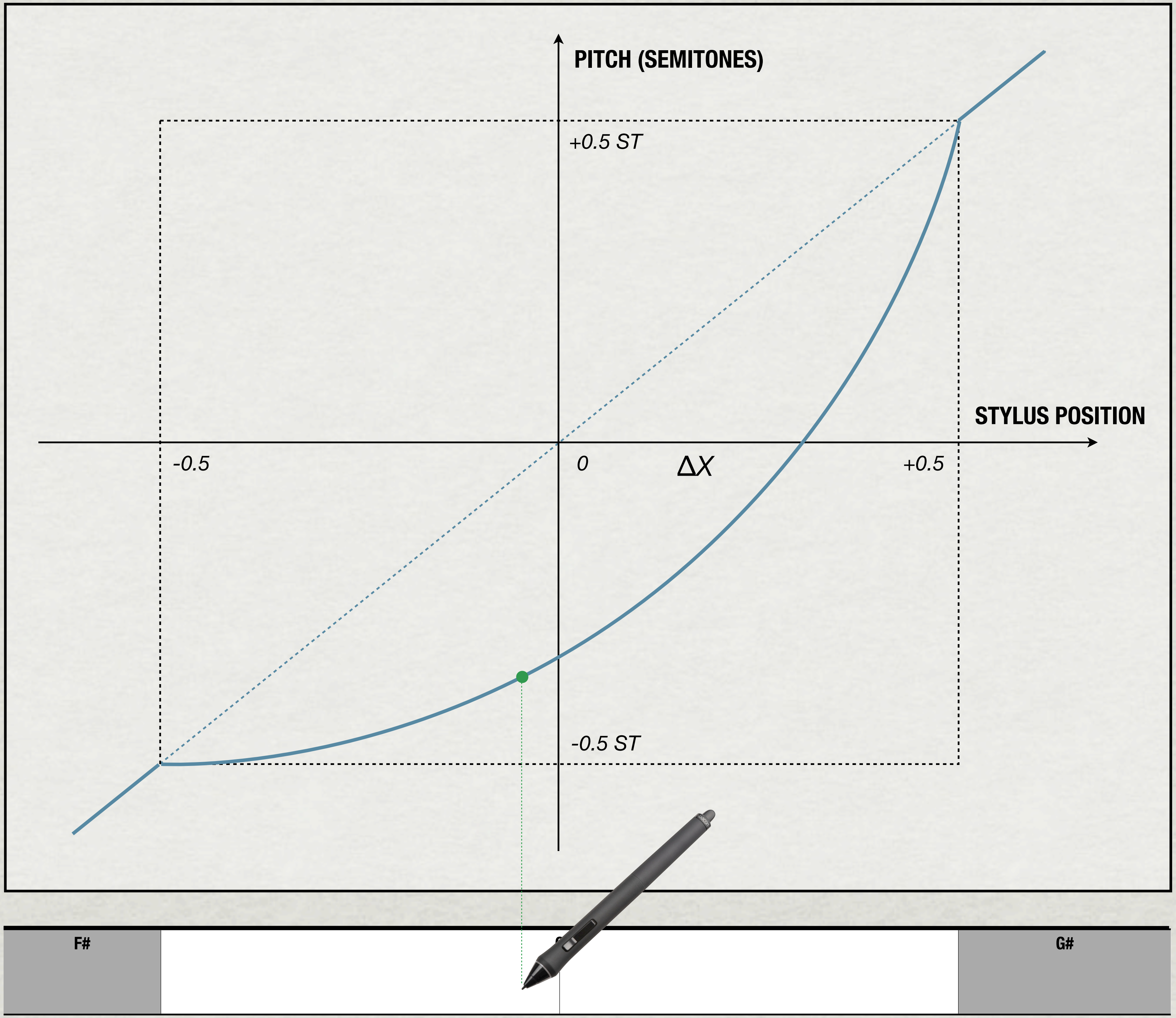
x_0 = pen position at contact
γ_0 = curvature at contact

Adaptive mapping algorithm



1. At contact: Curve goes through the position of stylus
   → Accuracy
2. Move inside the key: NL mapping
   → Expressivity
3. Go outside the key: Linear mapping everywhere
4. New contact: Back to 1.

Adaptive mapping algorithm



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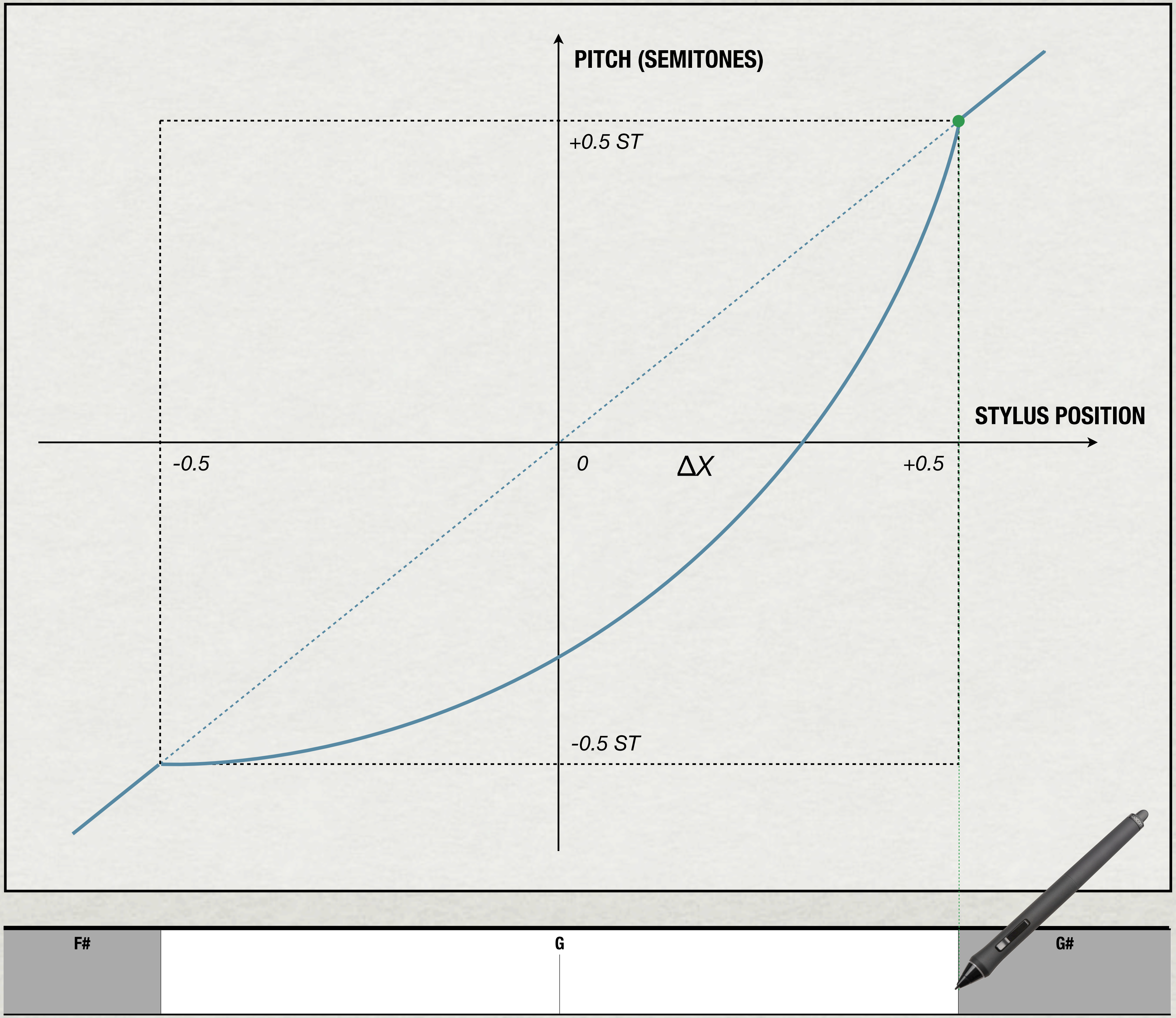

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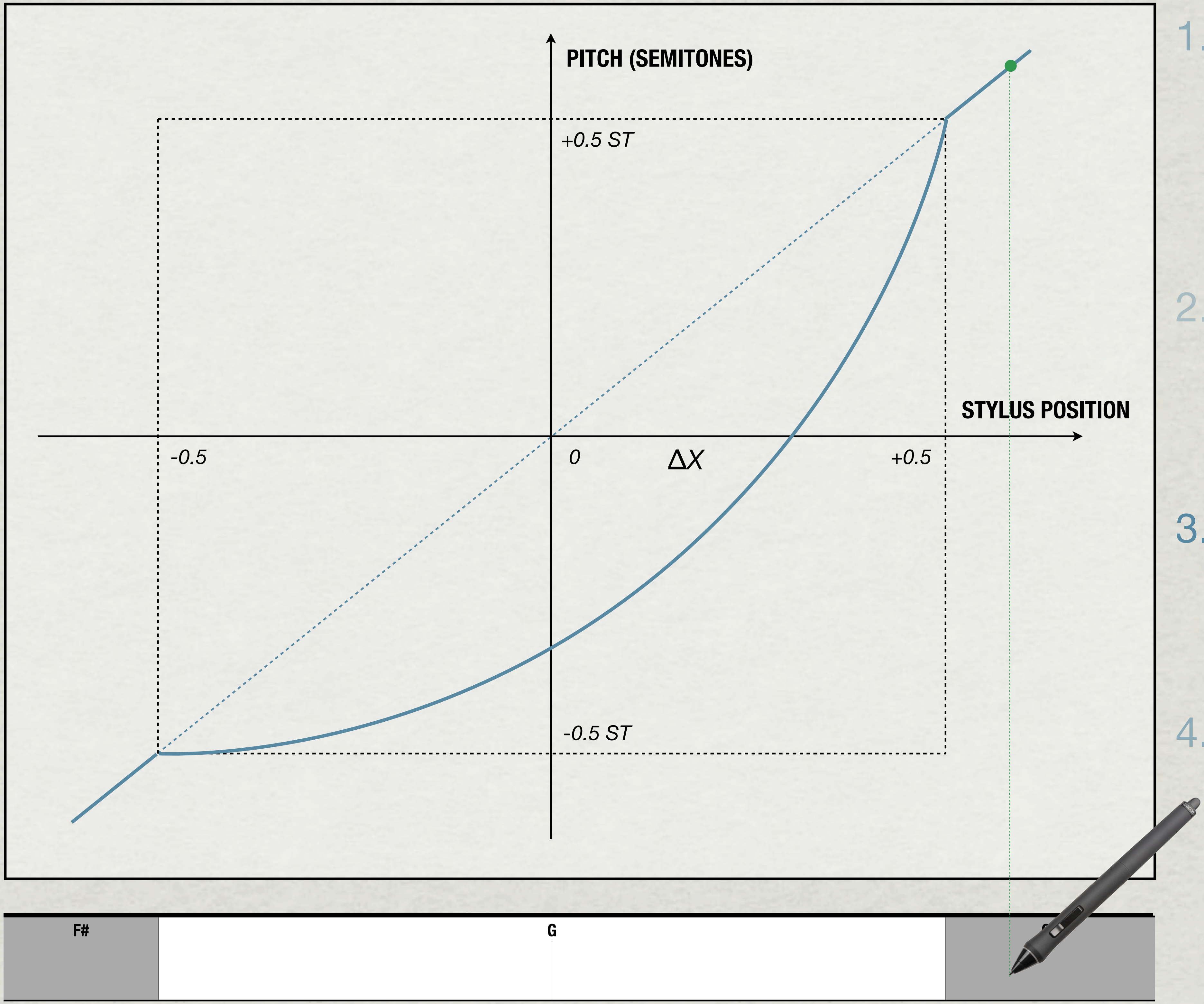

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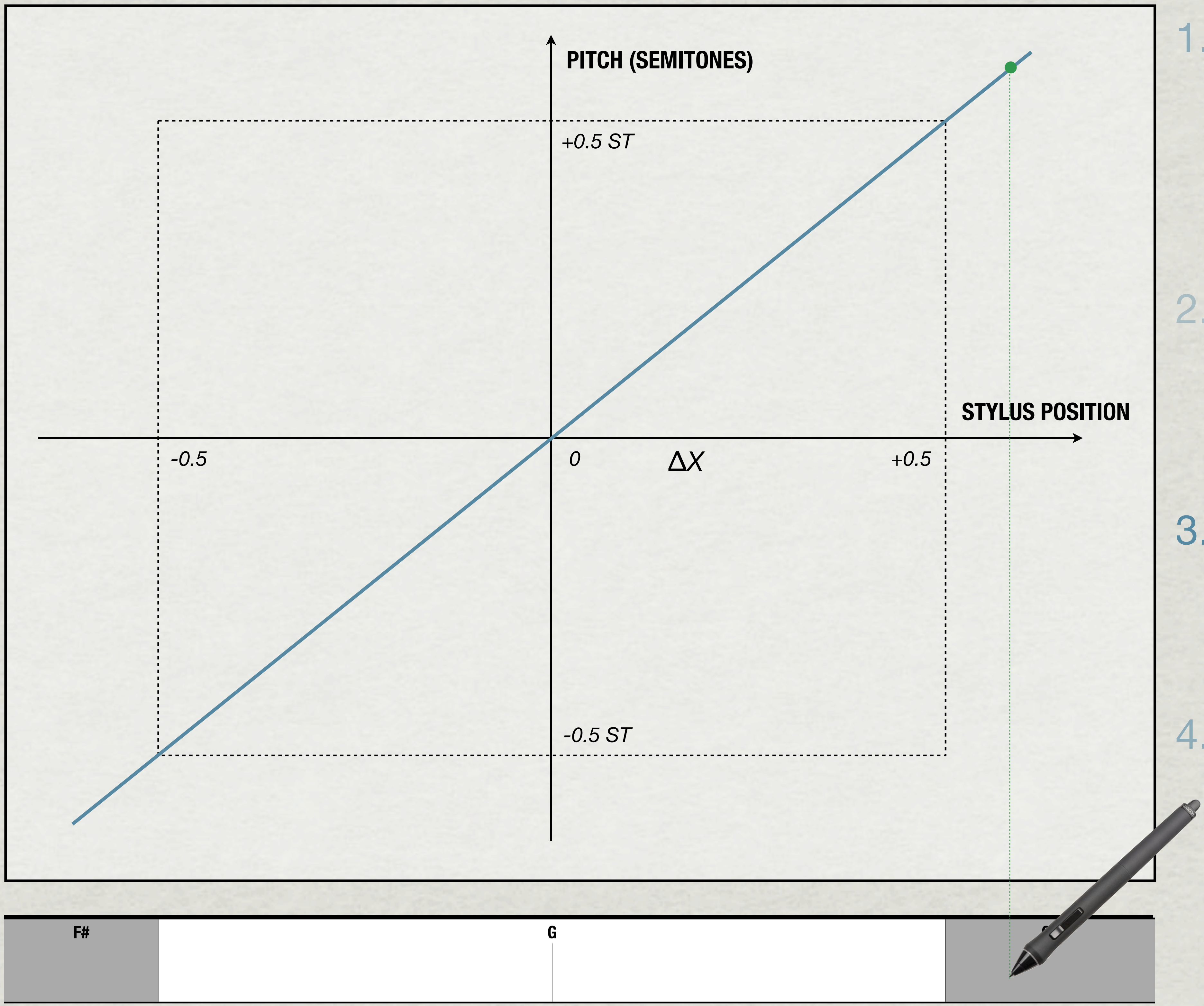

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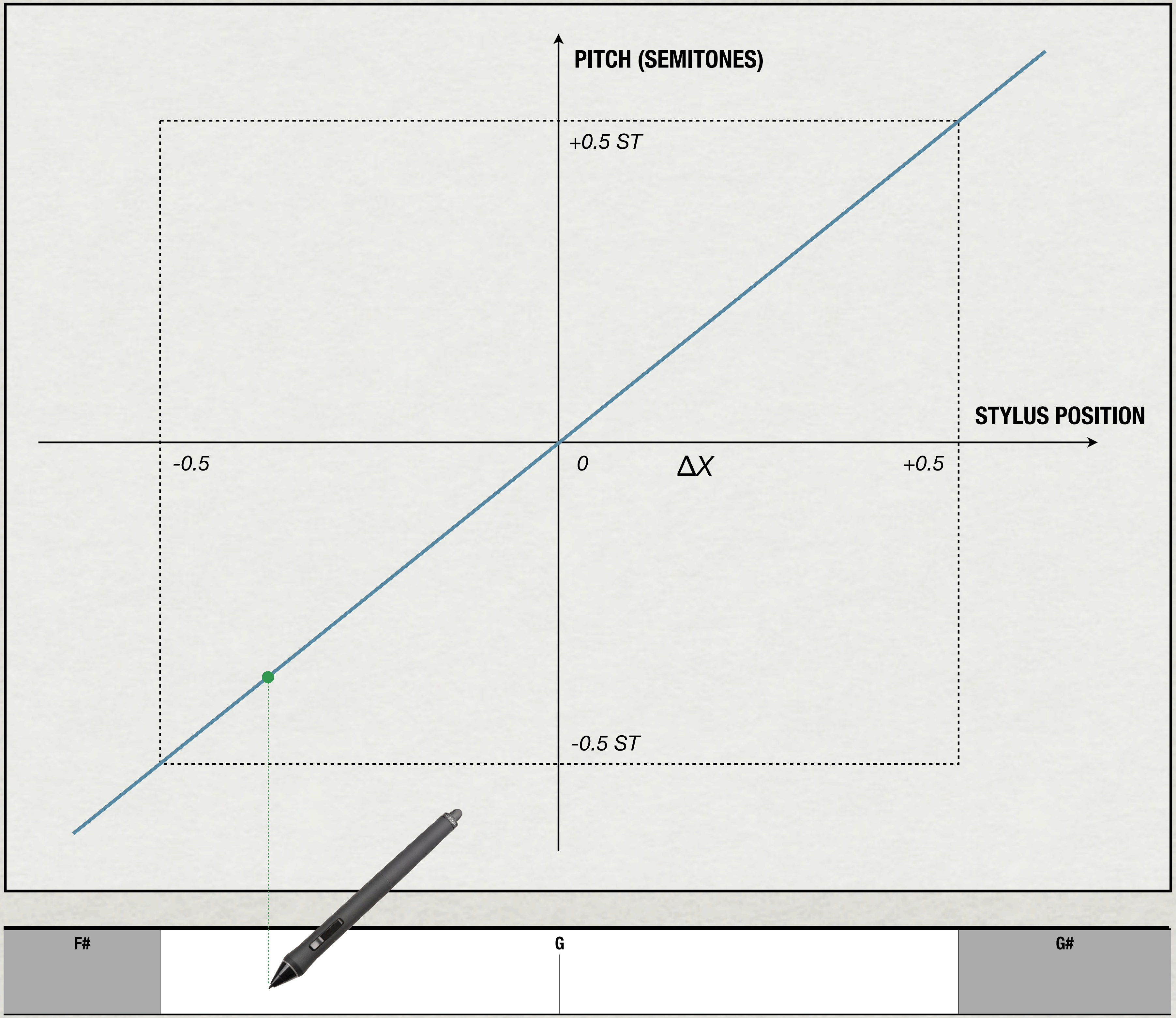

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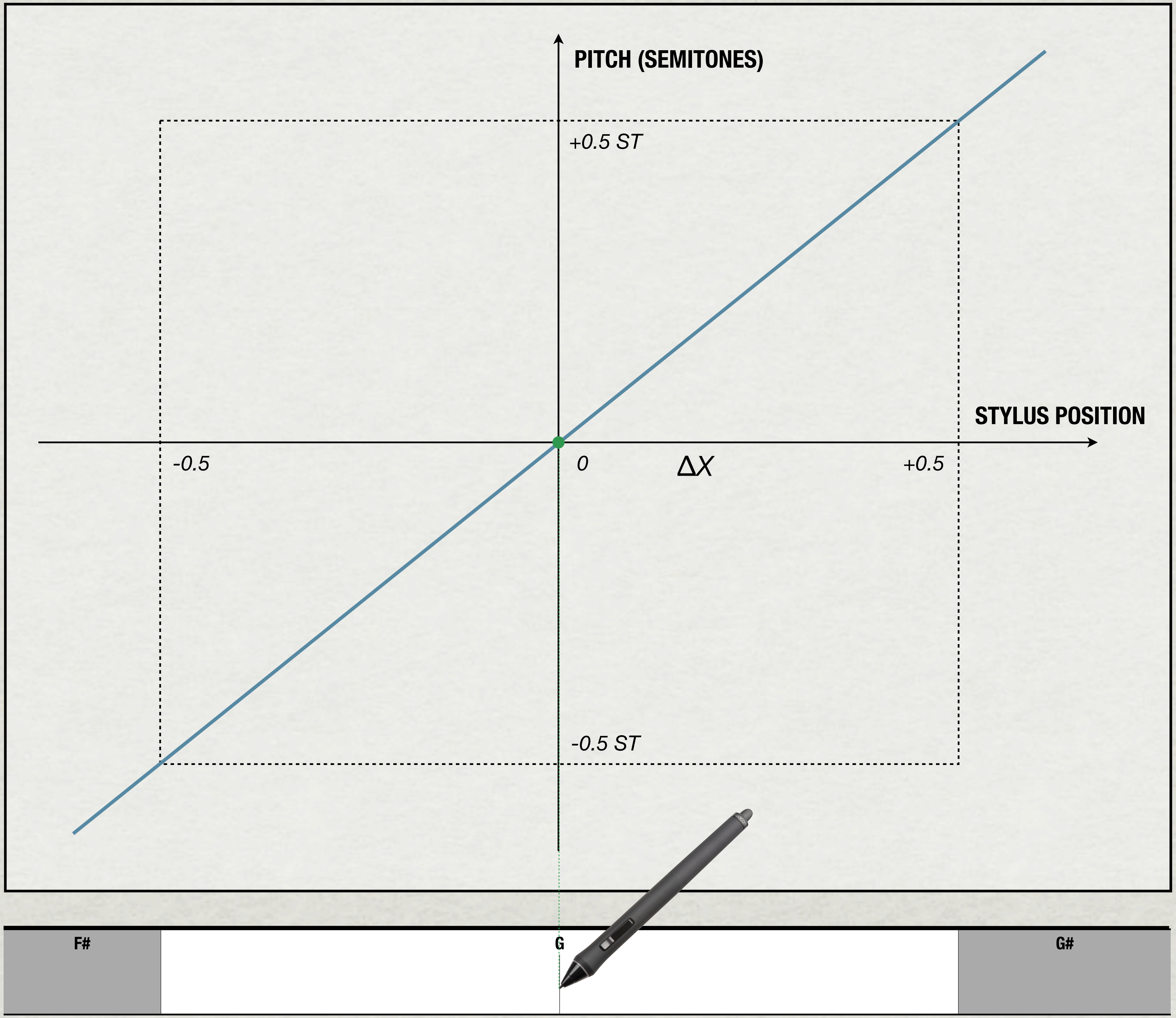

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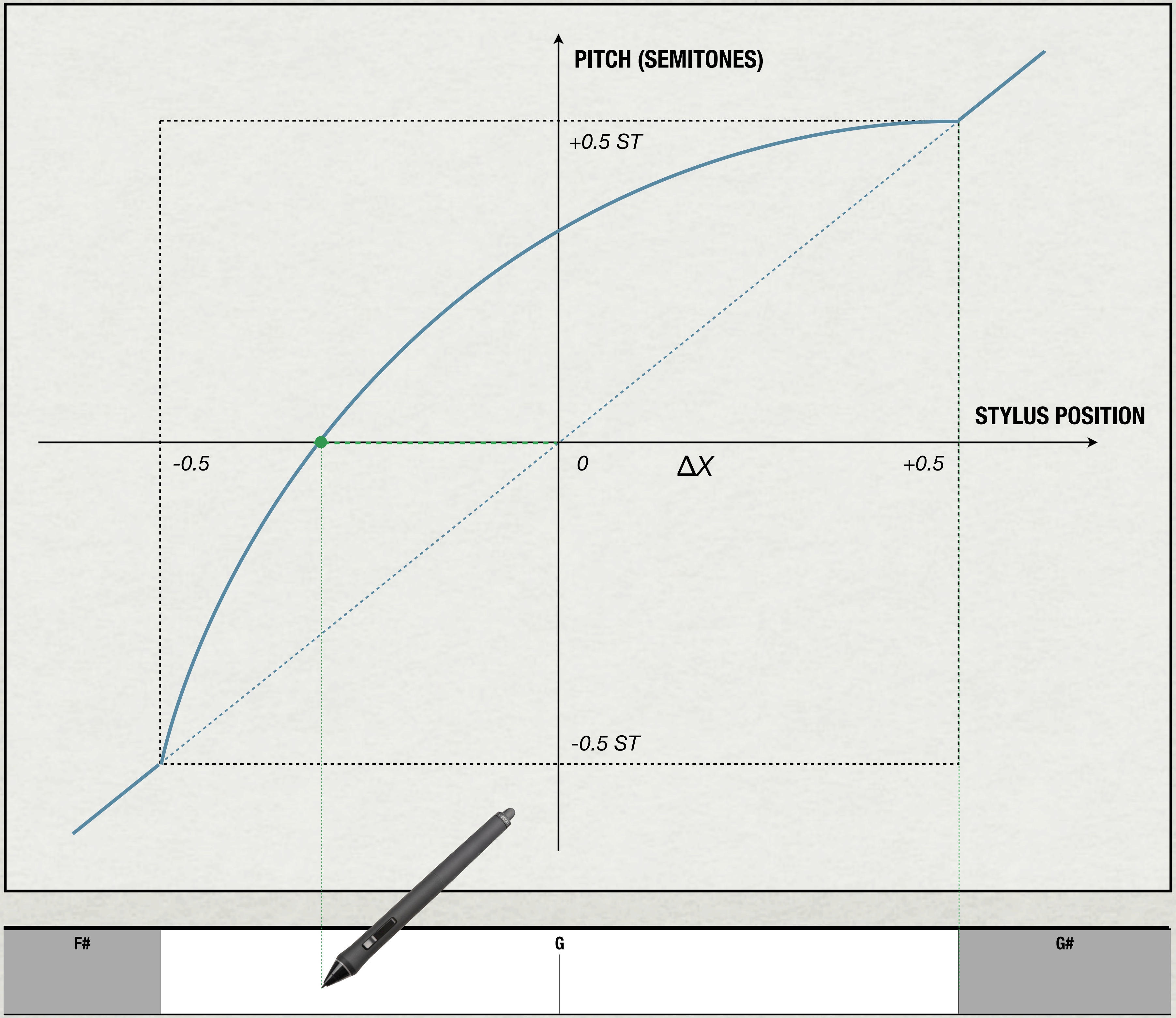

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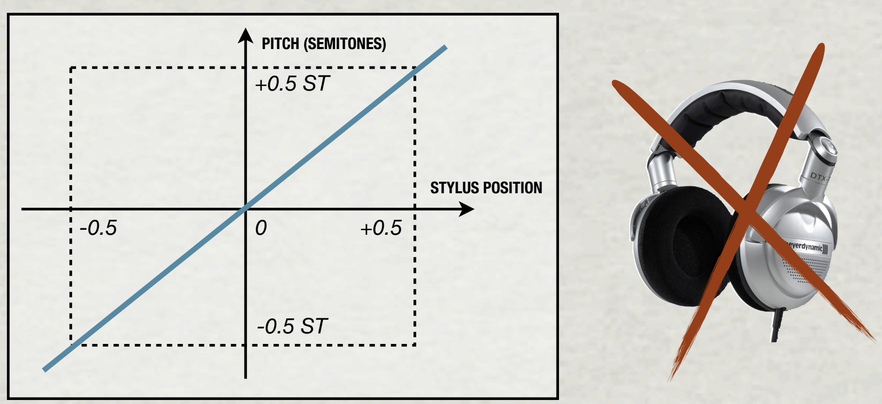
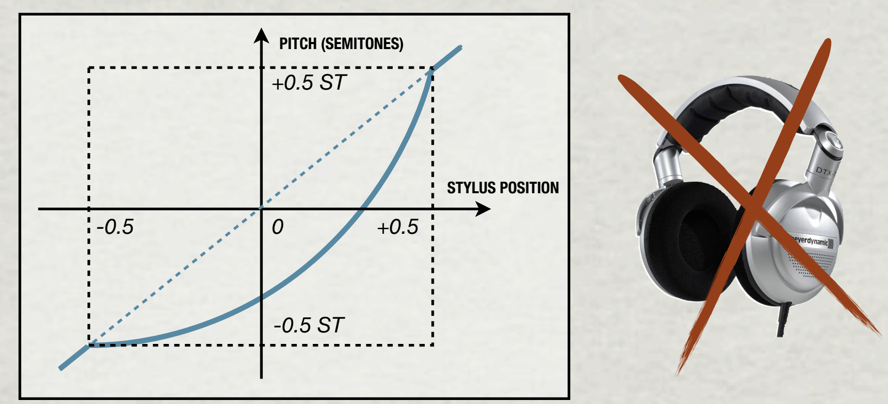
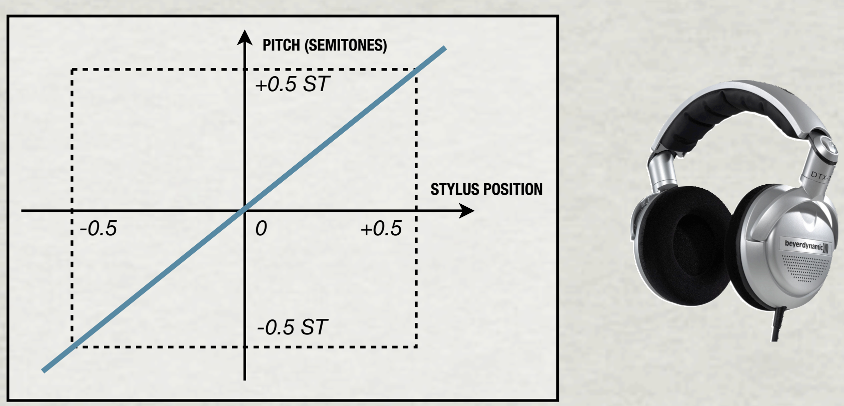
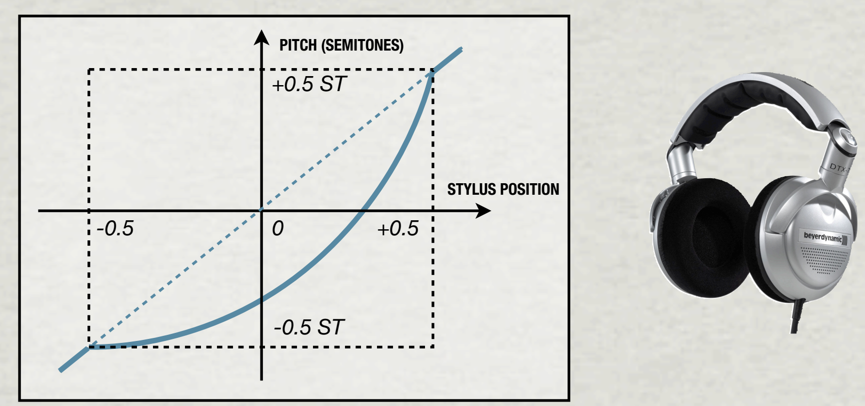
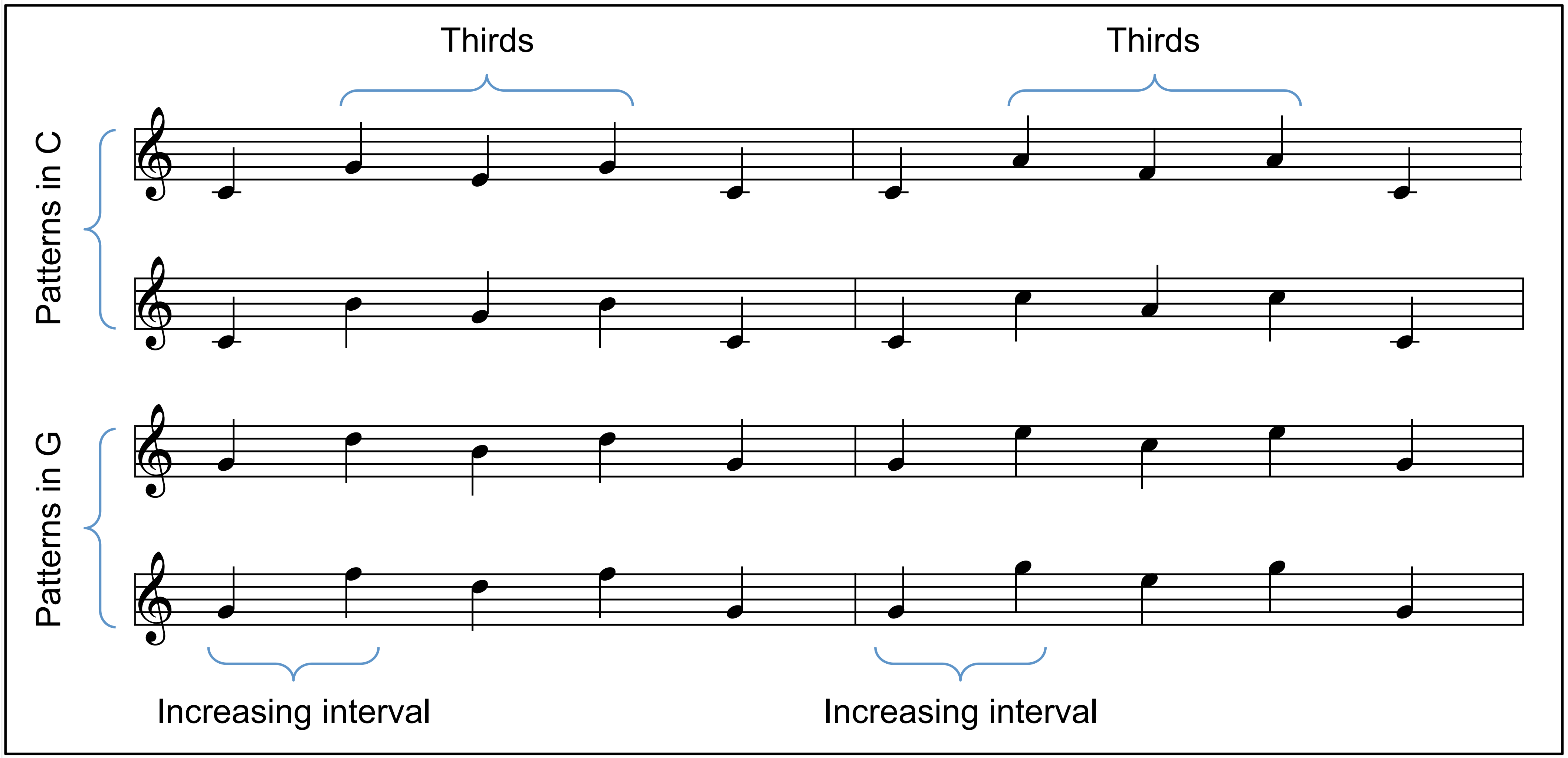
Experiment

- Compare performance of subjects with tablet in 4 conditions:

	No correction	Correction
No audio feedback		
Audio feedback		

Protocol

- Imitation of unfamiliar melodies: Alberti basses
  - Various intervals
  - Alternate forward / backward movements
  - Double exercise (transposition)

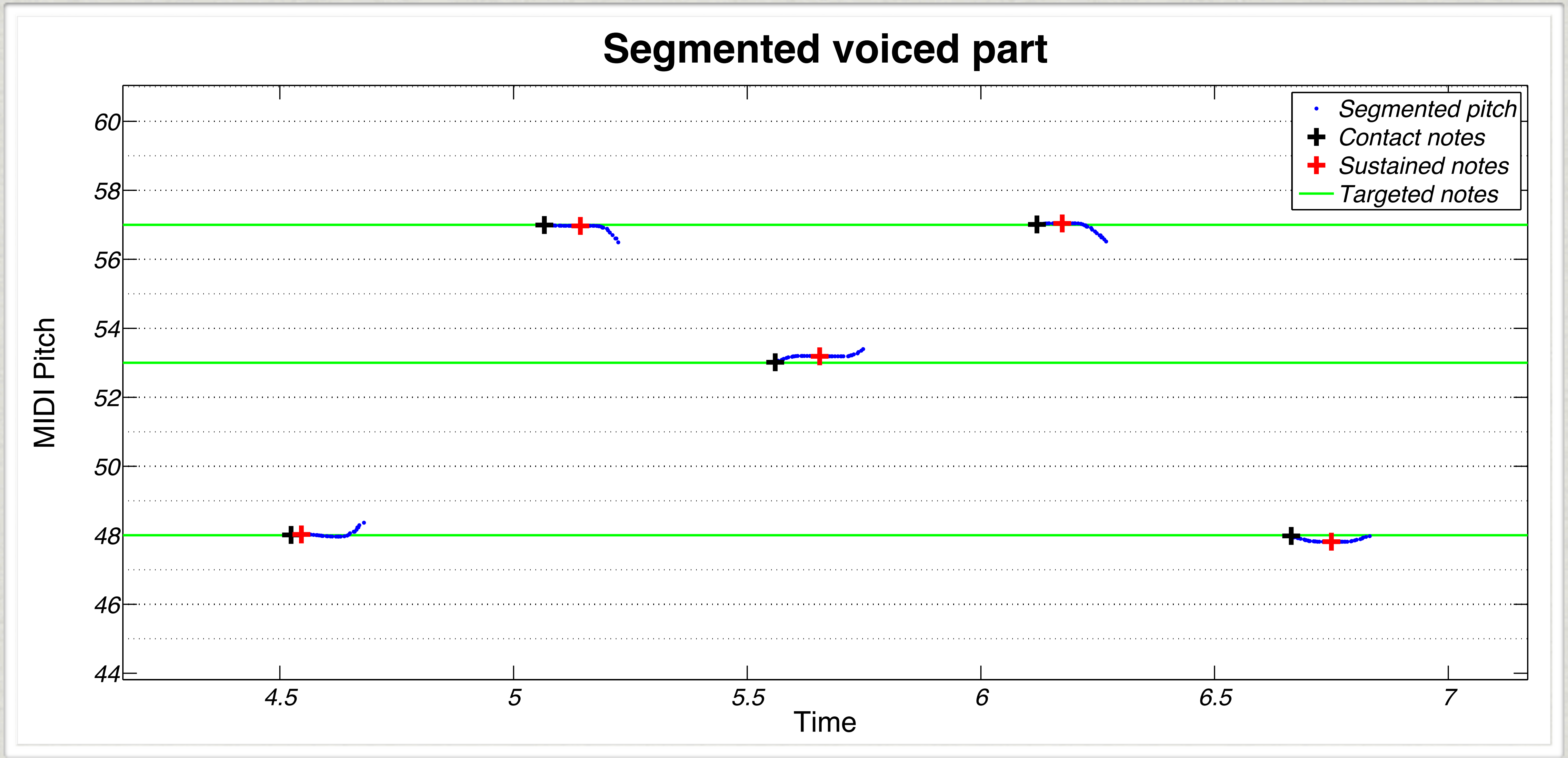


Protocol

- Imitation of unfamiliar melodies: Alberti basses
  - Various intervals
  - Alternate forward / backward movements
  - Double exercise (transposition)
- Protocol
  - Visual (score) and audio (MIDI) support
  - Fixed tempo: 120 b.p.m. (metronome)
  - New contact for each note
- Subjects
  - 7 subjects
  - Average age: 28
  - 50% musicians (average practice: 15 years)

Datas

- Data extraction
  - Value at contact
  - Sustained value (stylization)



Datas

- Data extraction
  - Value at contact
  - Sustained value (stylization)

- Measures
  - Accuracy

    Music: Ability to reproduce a note in tune

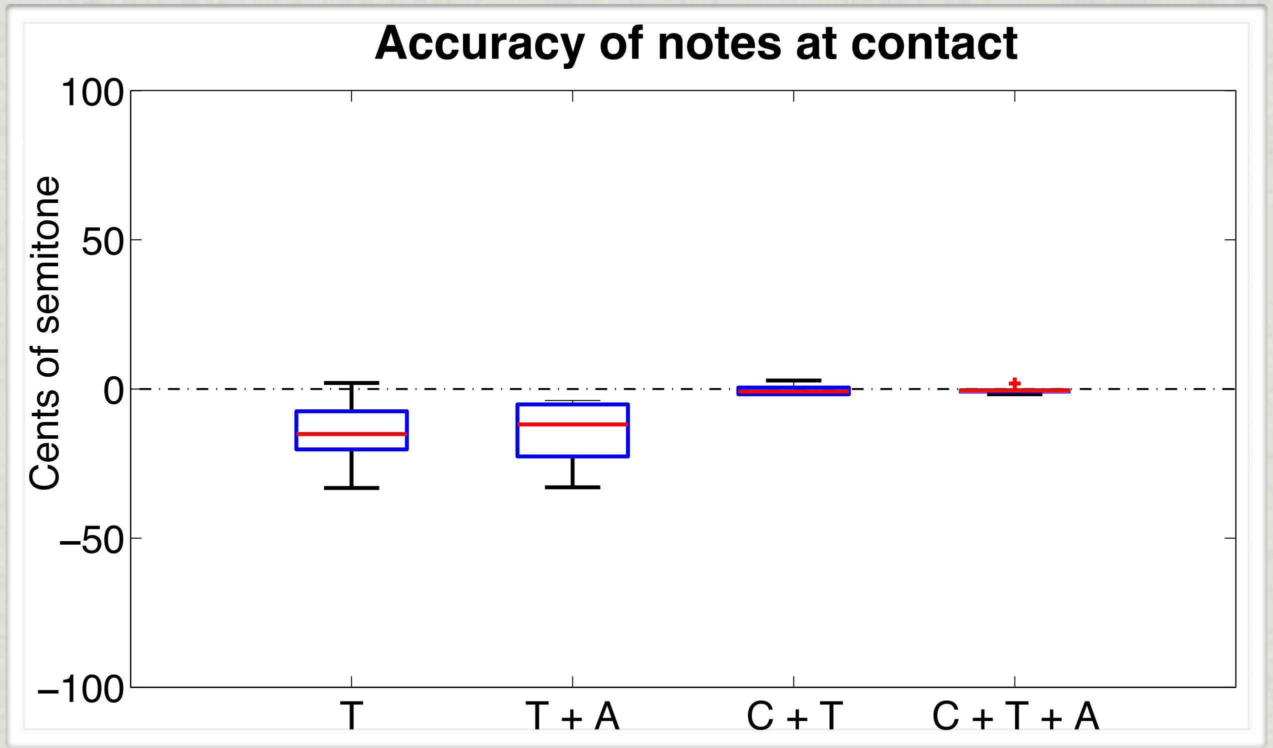
    Statistics: Mean of errors between sung notes and their targets

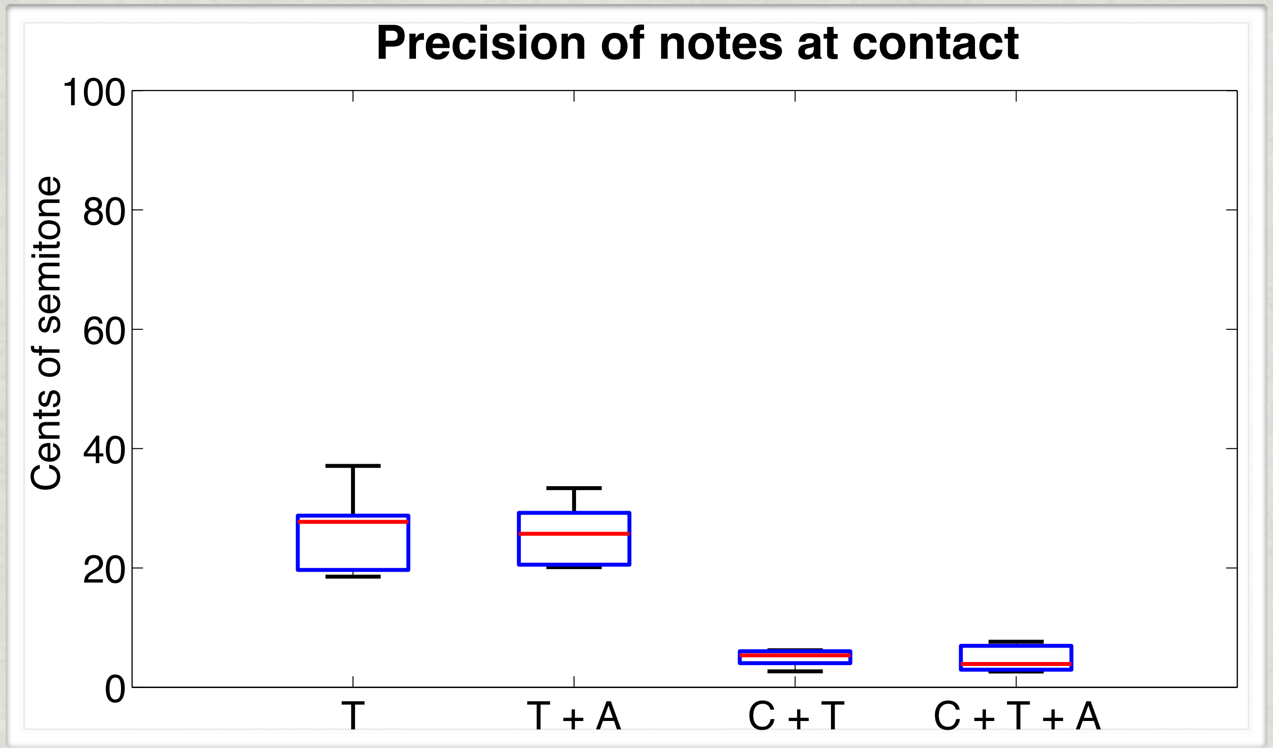
  - Precision

    Music: Pitch stability of the player

    Statistics: Standard deviation of the sung notes with same target

Analysis


Accuracy of notes at contact
Cents of semitone
100
50
0
−50
−100
T
T + A
C + T
C + T + A


Precision of notes at contact
Cents of semitone
100
80
60
40
20
0
T
T + A
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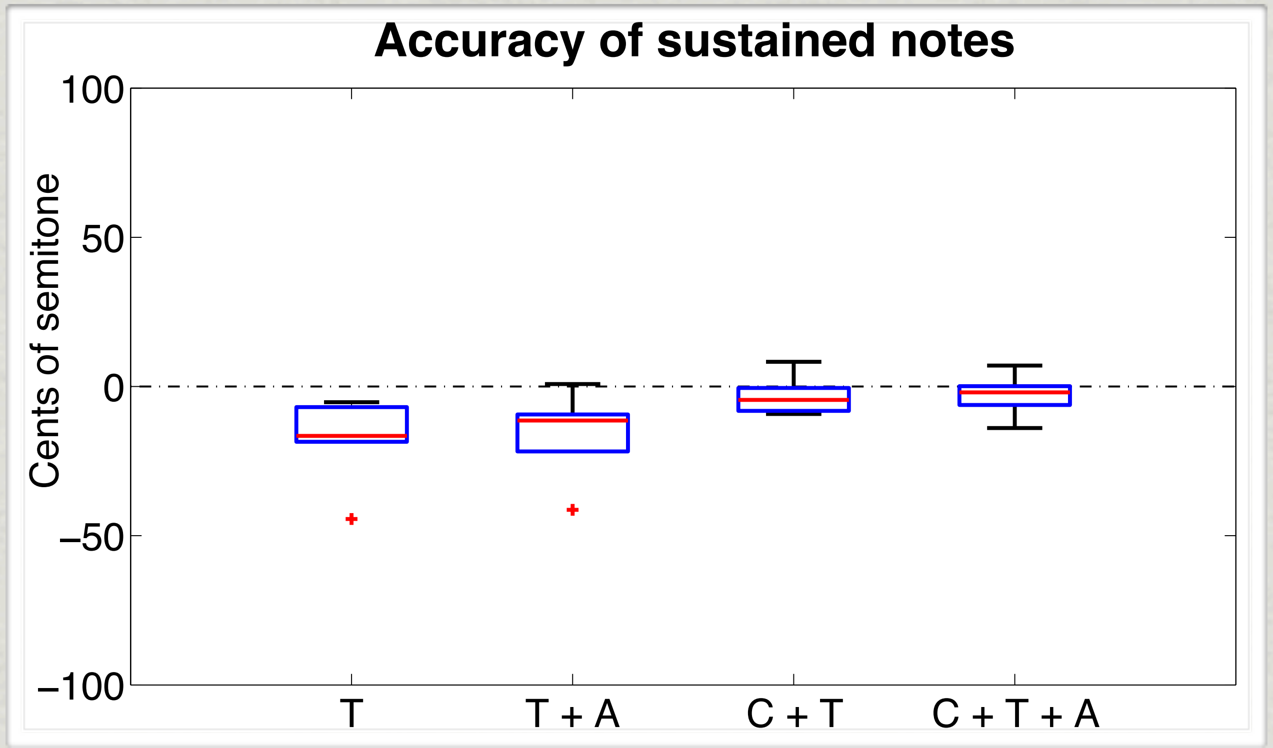
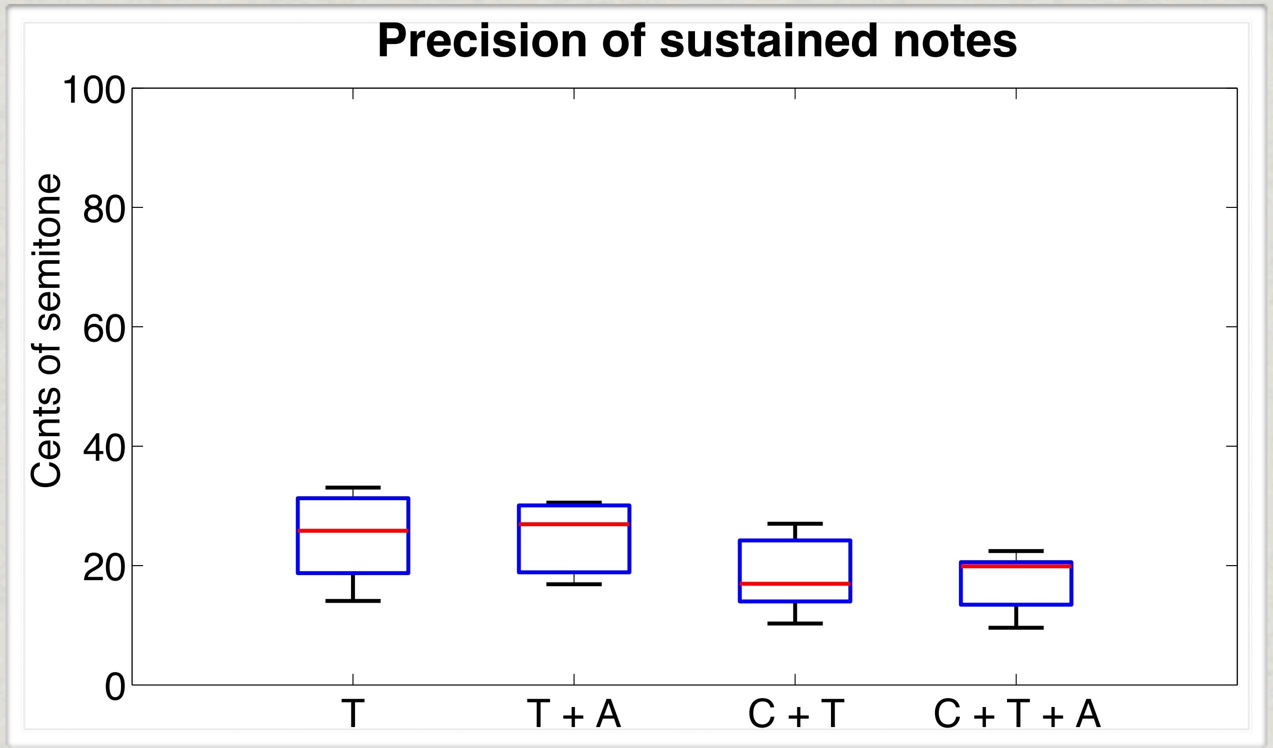
C + T + A


Accuracy of sustained notes
Cents of semitone
100
50
0
−50
−100
T
T + A
C + T
C + T + A


Precision of sustained notes
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80
60
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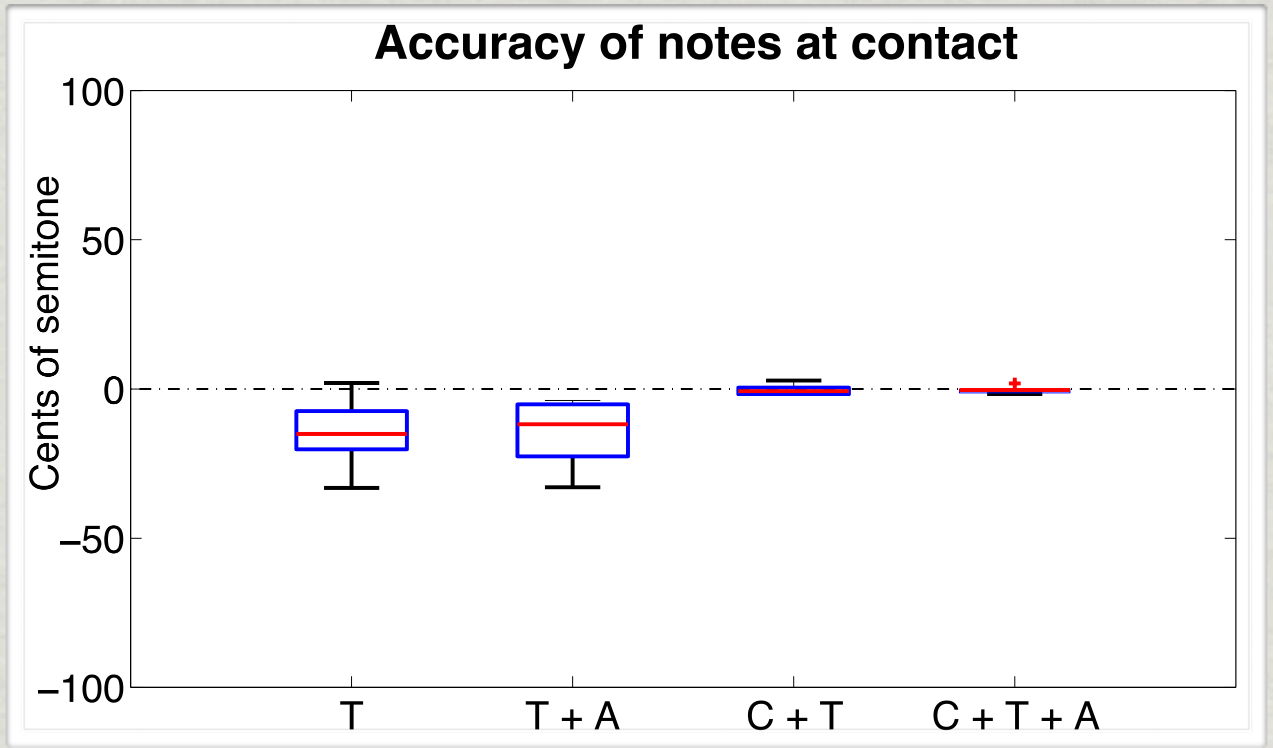
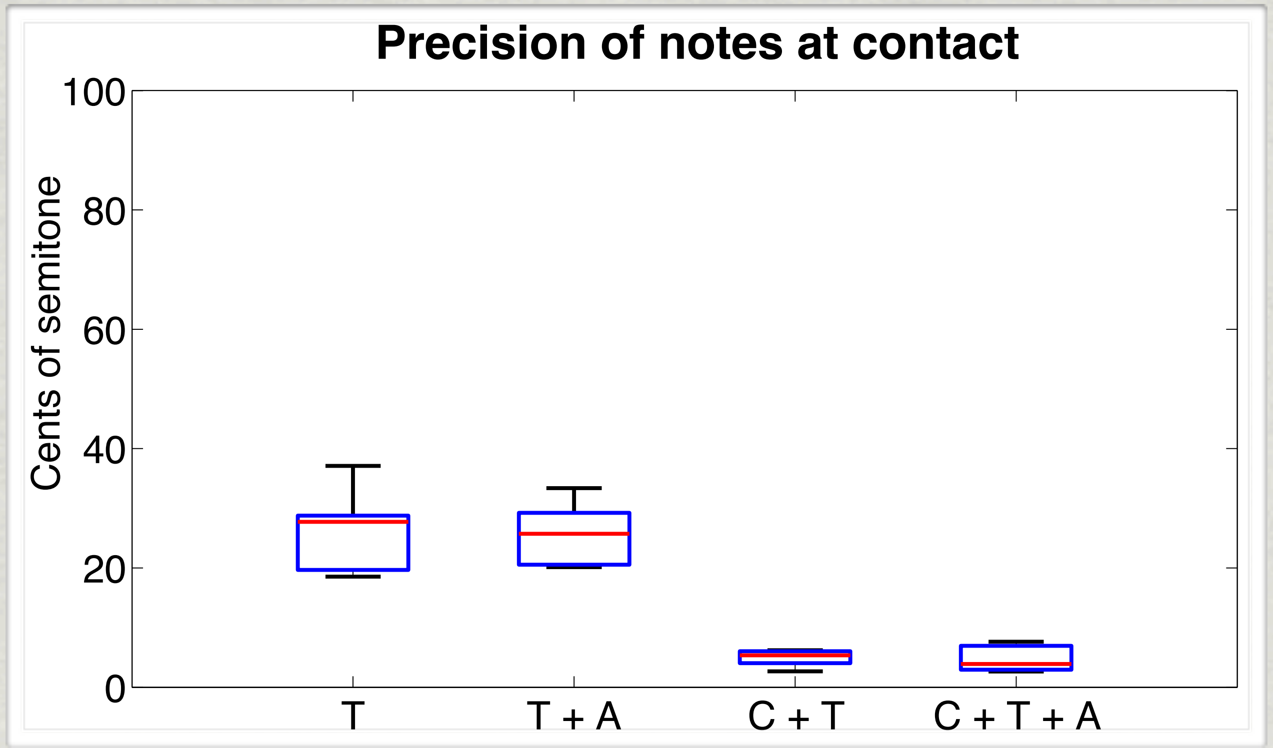
Analysis - contact



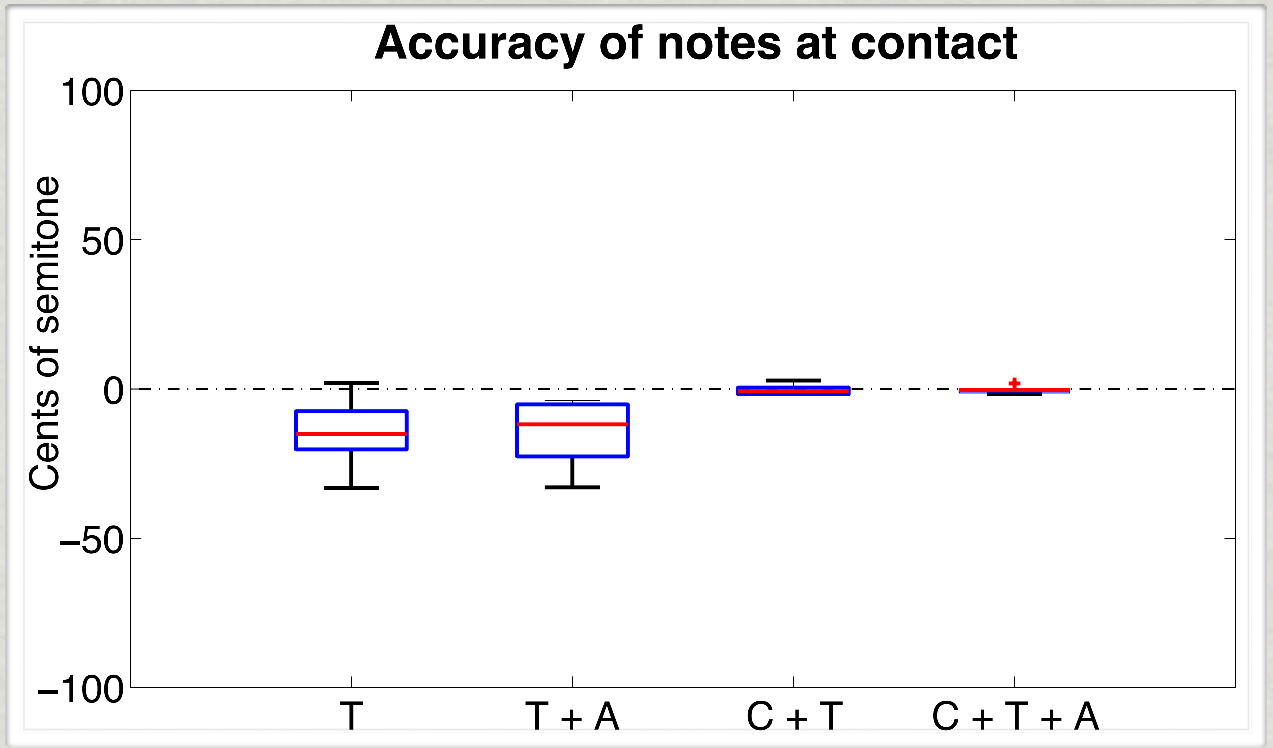


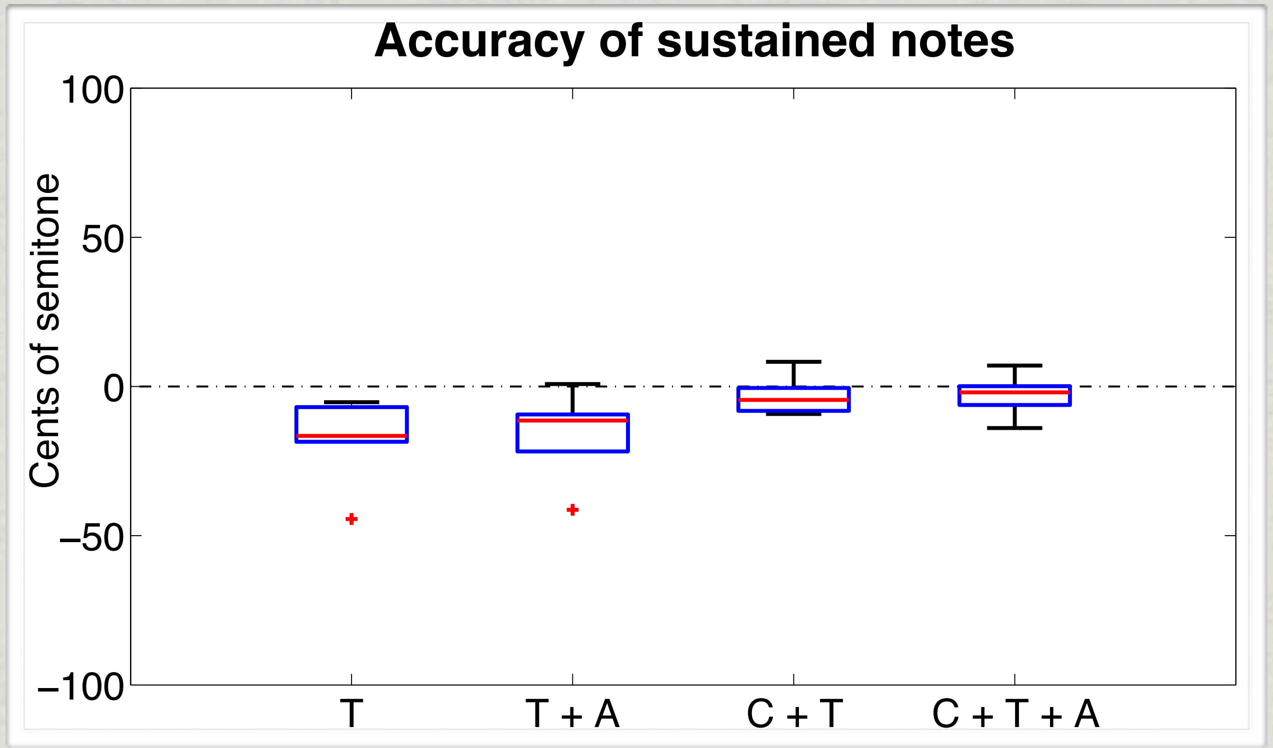
Accuracy		Precision
Median of values ~ -0.13 ST	Without correction *(T , T+A)*	Median of values ~ +0.26 ST
All values < 0.04 ST (threshold perception)	With correction *(C+T , C+T+A)*	Median of values ~ +0.05 ST

→ Algorithm helps the player to play in tune at contact

→ Algorithm helps pitch stability at contact

Analysis - accuracy

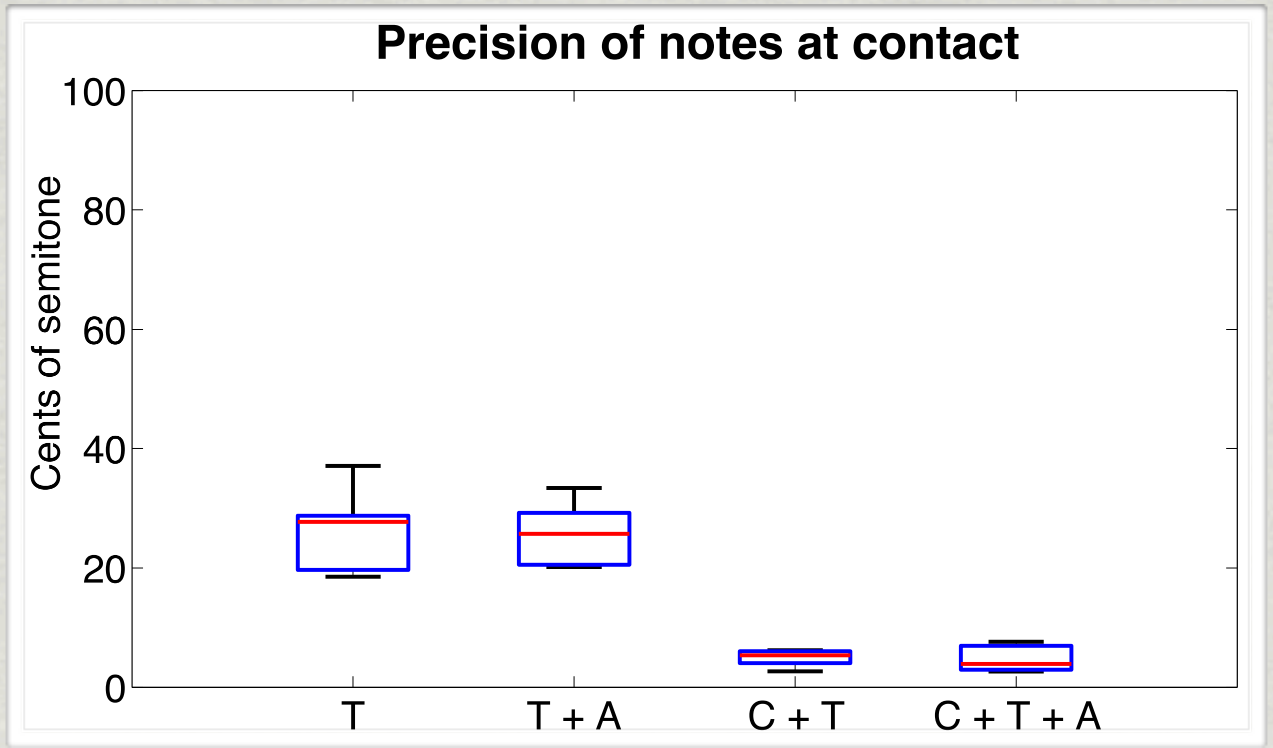


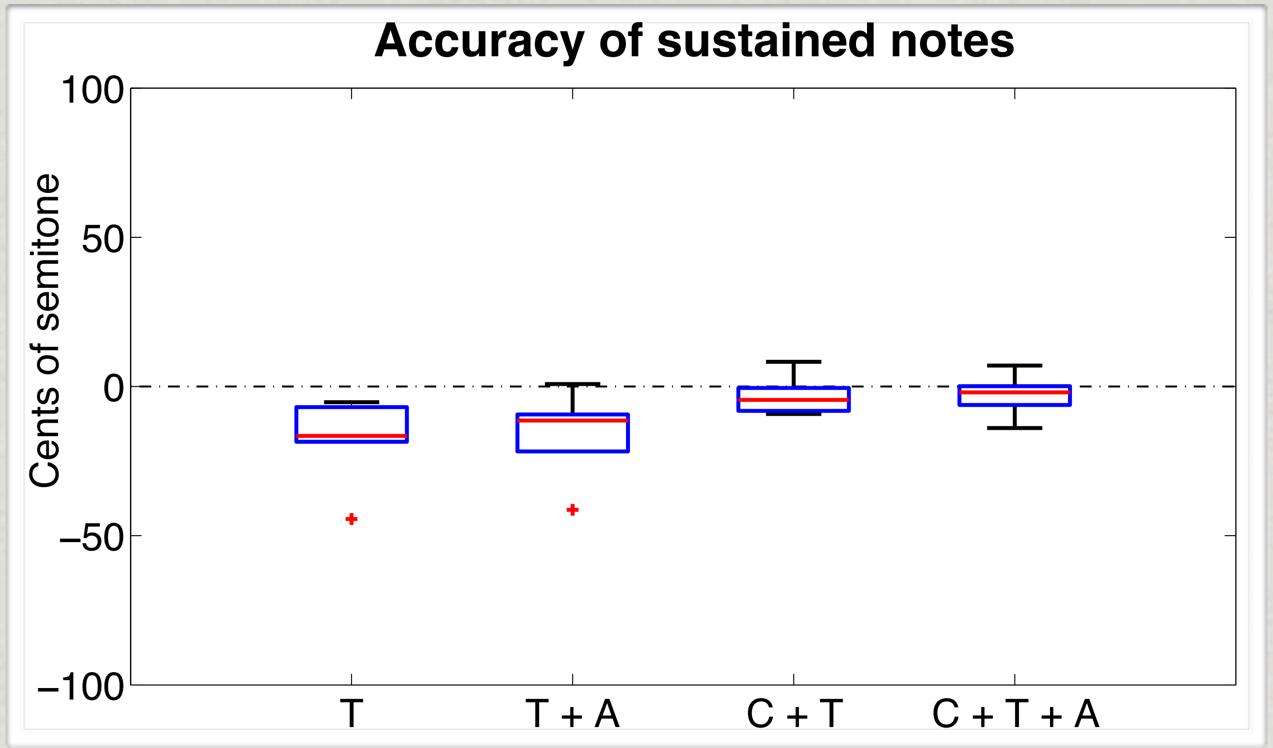


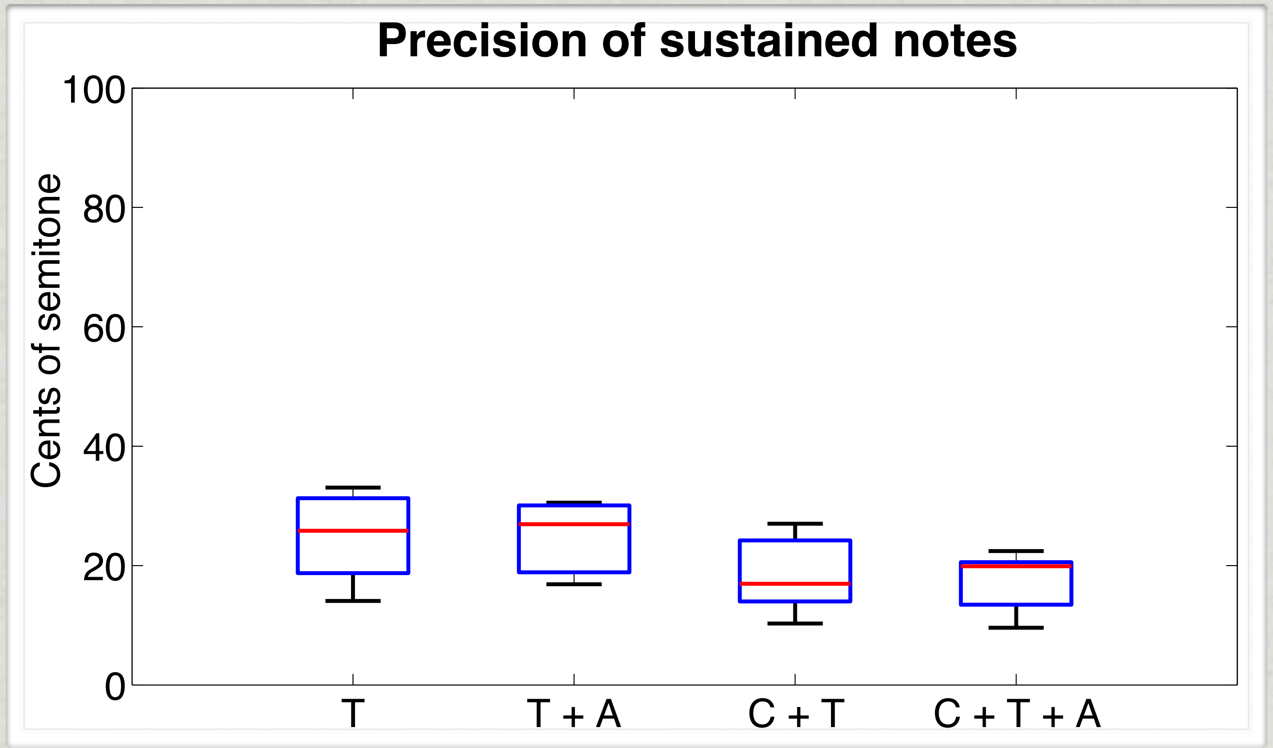
- Sustained notes
  - Improvement (median ~ 0.03 ST)
  - Larger dispersion / contact
  - → Movement of stylus
- With audio
  - Smaller deviation
  - → Feedback helps control
- All outliers corrected

Analysis - precision

- Fewer improvement
  - Small median improvement
  - Better with audio feedback
  - → Movement prevents pitch stability







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Conclusions

- Pitch correction in realtime
  - Improve significantly accuracy at contact
  - Few improvement on precision
  - Good perceptive results (no experiment)
- Continuous mapping after contact
  - Allow expressivity
  - Limit: natural deviation of stylus
- Further work
  - Conduct perceptive experiments
  - Conduct experiments with touch interfaces (fingers)
- Evening concert tomorrow !

Accuracy and precision

- **Accuracy**

  Mean of errors between sung notes and their targets

$$A = \frac{\sum_i^N (S_i - T_i)}{N}$$

- **Precision**

  Standard deviation of notes with same targets

$$P_{PC} = \sqrt{\frac{\sum_i^{N_{PC}} (S_i - M_{PC})^2}{N_{PC}}}$$

- **Notations**

  S_i = sung note indexed by i

  T_i = note target indexed by i

  N = number of notes in a melody

  M_{PC} = mean of all sung notes with same target (pitch class)

  N_{PC} = number of notes with same target (pitch class)