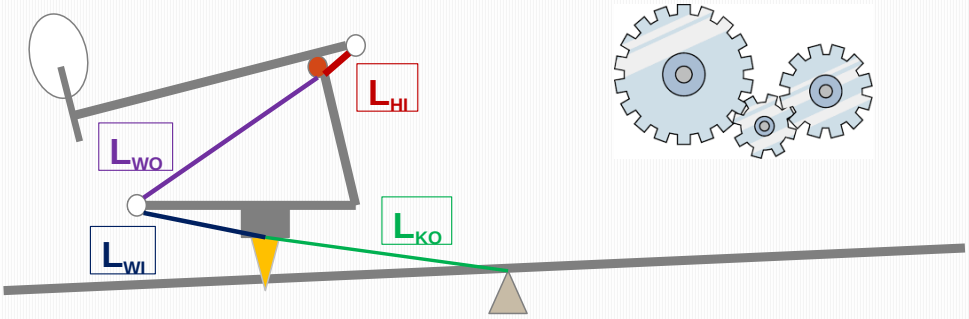
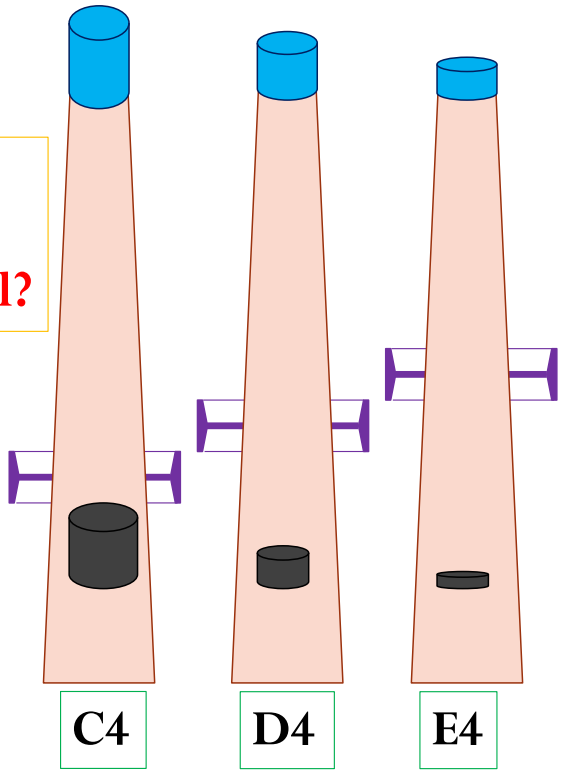
Understanding “Moment of Inertia”



Yuji Nakamura, ARPT, NZ

Adjusted at
same DW & UW.
How did you feel?



These 3 notes have same BW, but they may have different feeling at kinetic movement.

Traditional "Touch Weight"

- is indicated by combination of down weight and up weight

(Example: DW = 52 g & UW = 26 g)

"Down-Up syndrome"

"Down & Up weights" followers believe this combination indicates weight of touch.

D & U followers include major manufacturers.

Dynamic Touchweight

Touch weight felt while playing

"Measurement of DW & UW doesn't stand actual playing as they were measured by movement at less than pp playing"

Explanation of "Dynamic Touch Weight"

by Mario Igrec

(From Pianos Inside Out)

Inertia, or **"dynamic" touchweight,** affects how much force is needed to play loudly, and is a function of strike (hammer) weight, action leverage, and the amount of leads in keys

Mario doesn't show the details how each component affects to Inertia.

Explanation of "Dynamic Touch Weight"

by David Stanwood

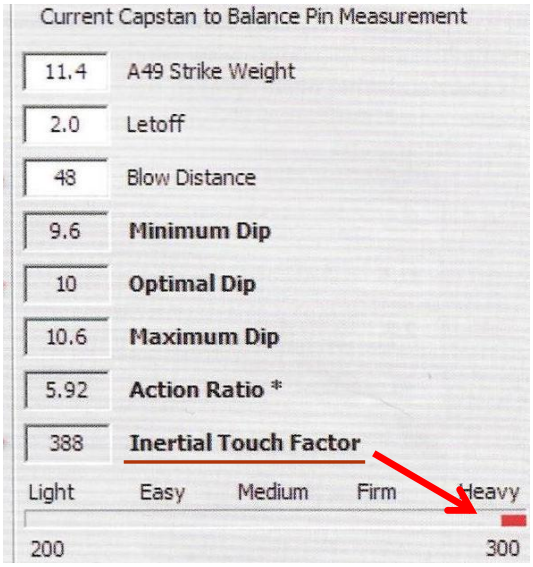
at Piano Price Point website

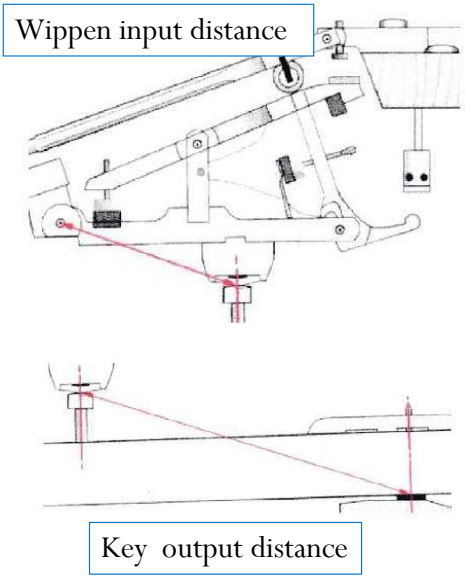
- My approach is to design and make dynamic touch by building touch weight components to precise engineered specifications. This sets the stage for the dynamic quality of the action.
- This results in a specific dynamic touch quality that is perfectly consistent and predictable from key to key when played.

Concept of PTD gives good tidy inertial balance, but it doesn't go into that direction.

Approach to inertial effect in the piano action

by Darren Fandrich & John Rhodes





They introduced numerical inertial effect into touch analysis but didn't show its details.

Approach to adjust inertial effect in the piano action

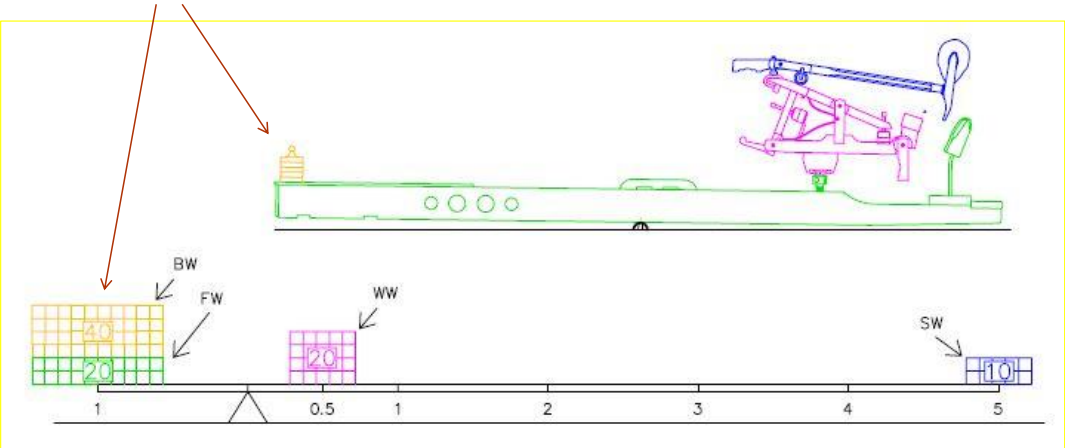
by Yuji Nakamura

"Touch Weight Management"

- Manage two touch weight indexes together;
  - static "Balance Weight" and
  - kinetic resistance "Moment of Inertia"
- Understand theory and concepts to manage touchweight

What is “Balance Weight”

BW+FW= WW x KR + HSW x SR

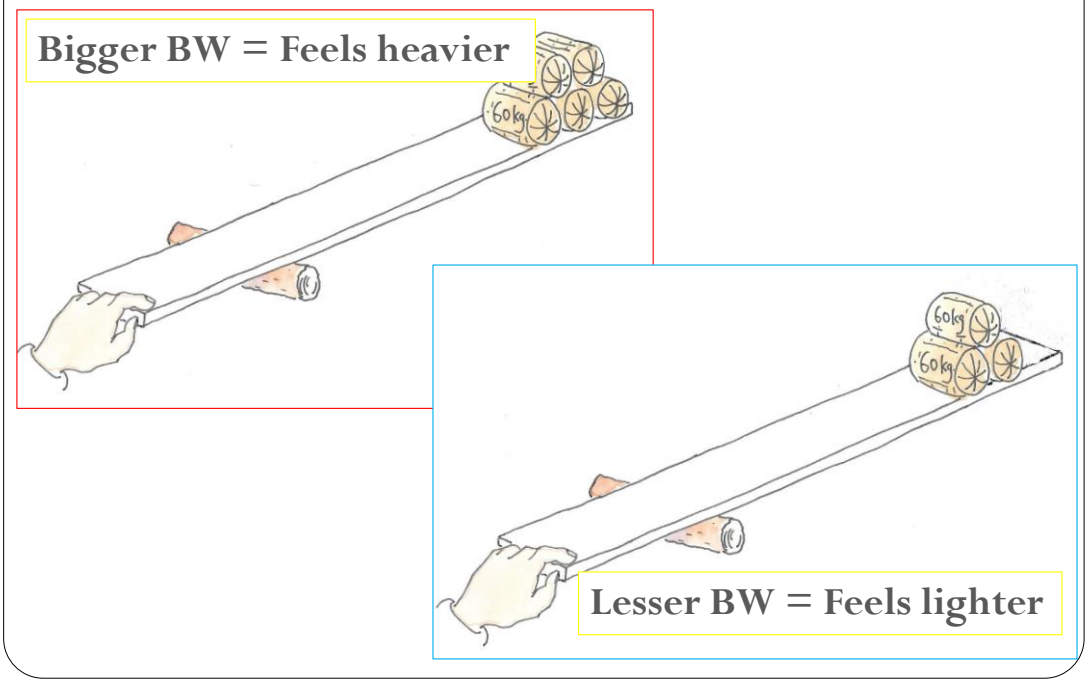


BW = (DW + UW) / 2

Seesaw model by David Stanwood

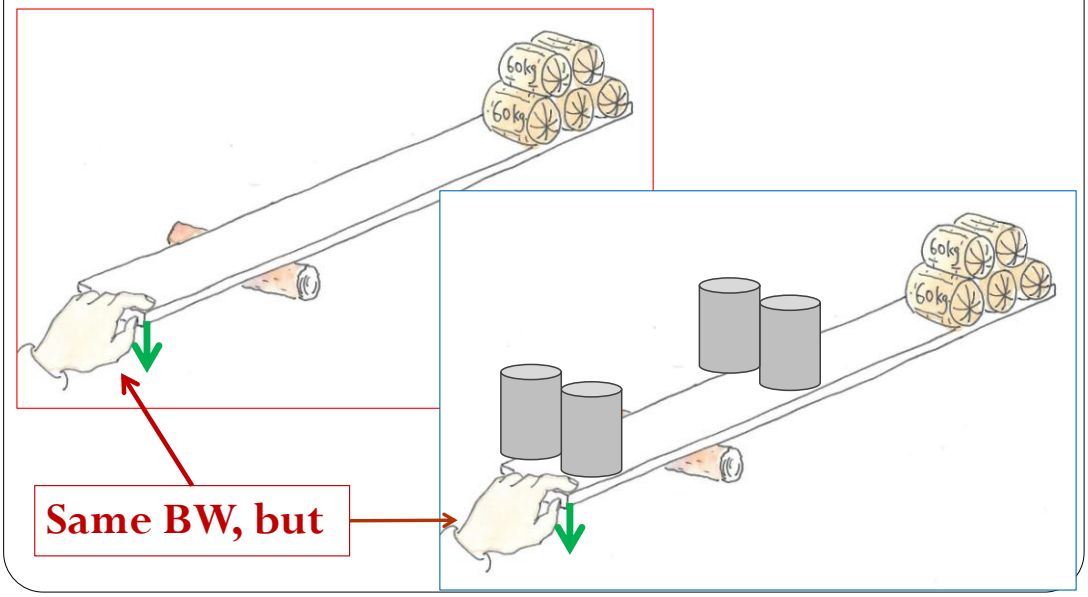
Your seesaw model & equation of balance are the best way to explain static touchweight.

Static touchweight: Balance Weight



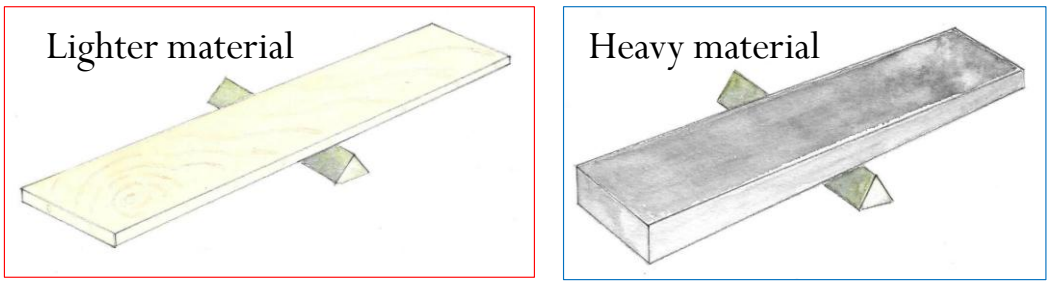
Kinetic touchweight: Different from BW

Same BW doesn't mean they feel same "touch weight"



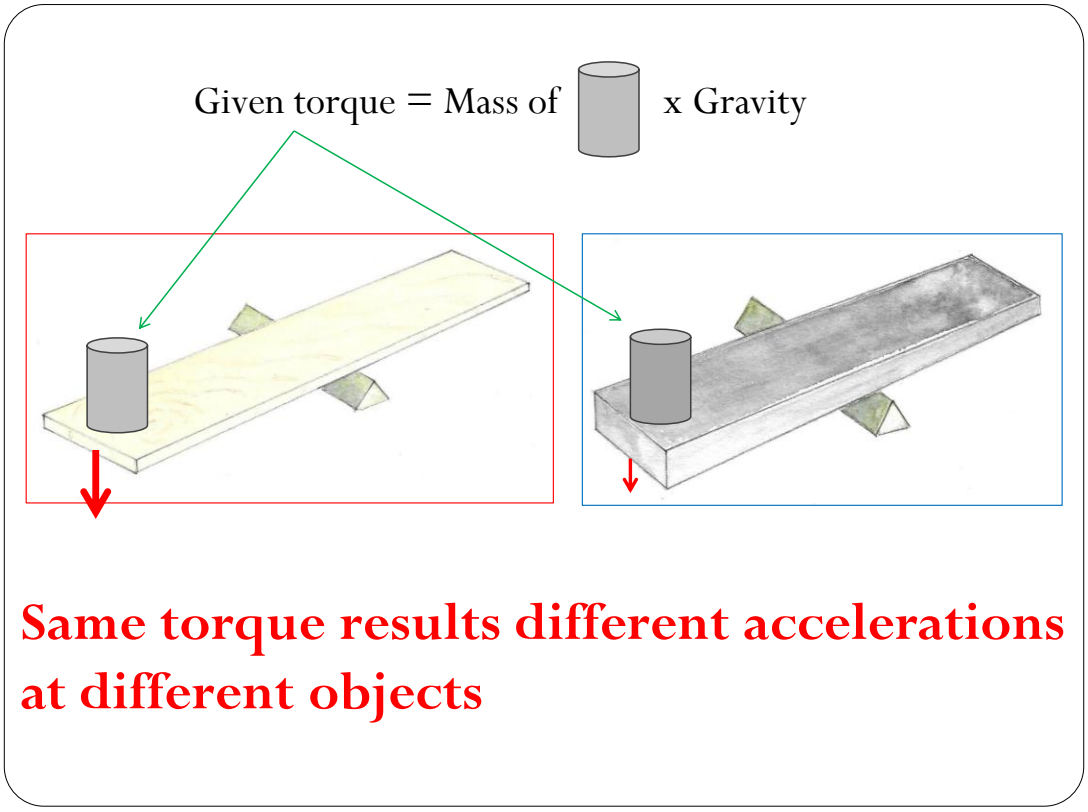
However there is a question whether BW is the only indicator of touchweight.

What is kinetic touch weight?

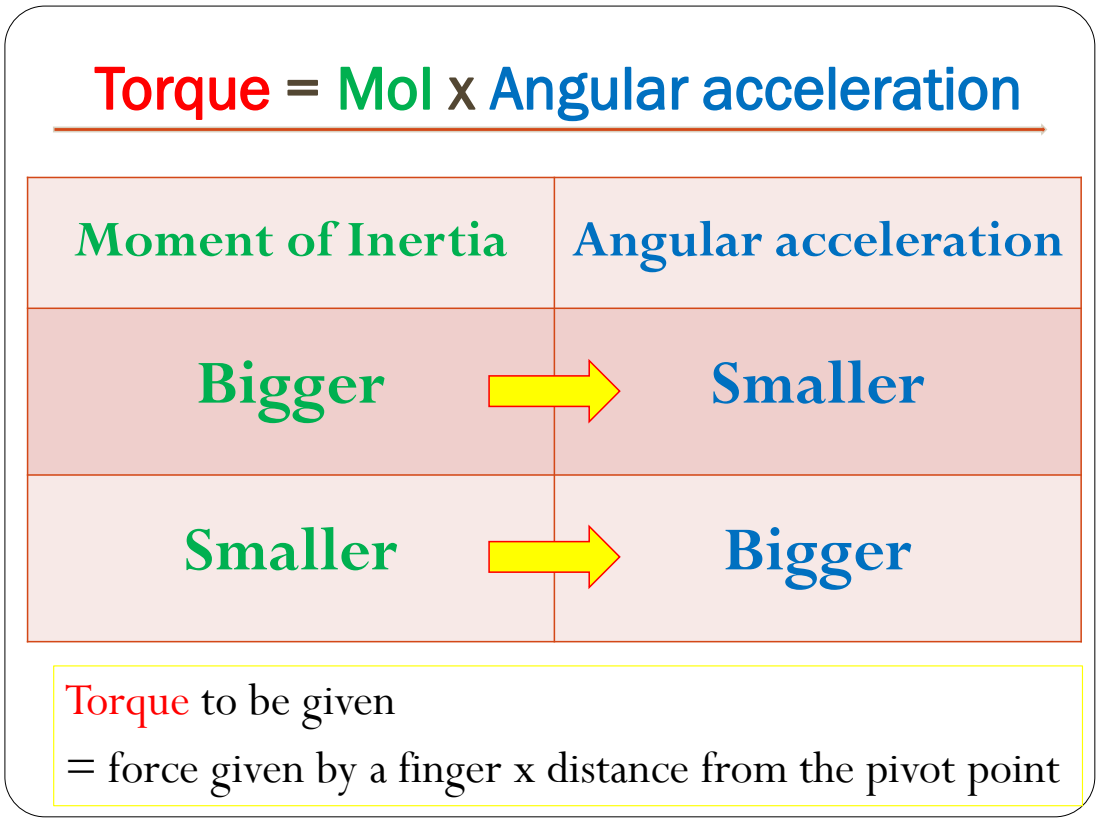


Both lever has balanced = Zero Balance Weight

How are both levers moved by "same force" ?



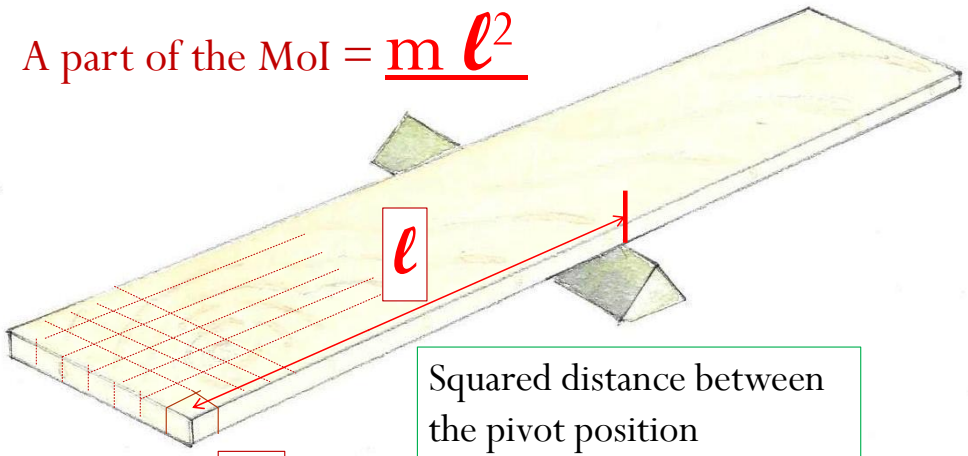
Wooden seesaw would move much quicker than metallic one by same weiight.



Theory shows their acceleration is depending on un-move-ability “Moment of Inertia”.

How to calculate MoI

A part of the MoI = $m \ell^2$



Squared distance between
the pivot position
and mass center of the part

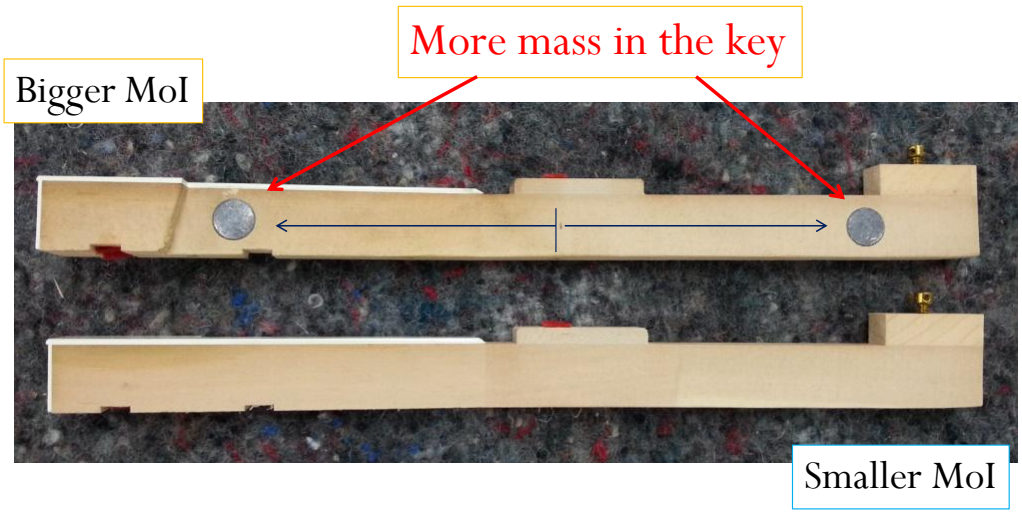
m

Mass of a part

Compare two keys with different length

MoI is bigger when each mass part has more distance from pivot point and each mass is heavier.

Compare two keys with same length

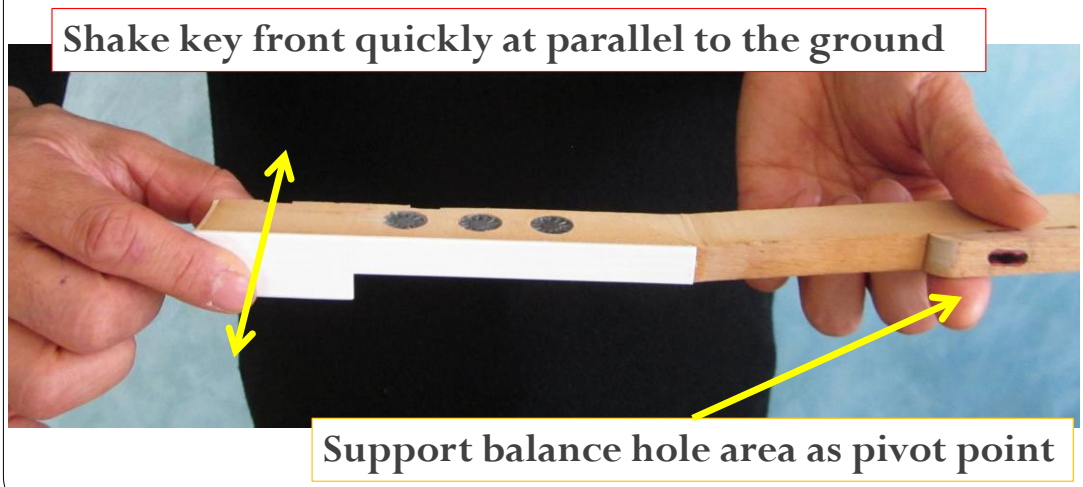


Two key sticks have different MoI due to additional key leads even they have same length.

Experience MoI of a key stick

What do you feel when giving torque to the key?

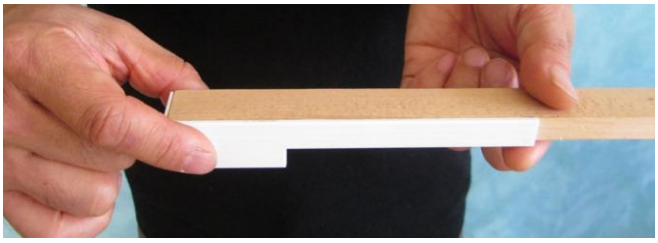
- **Resistance of movement = Moment of Inertia**



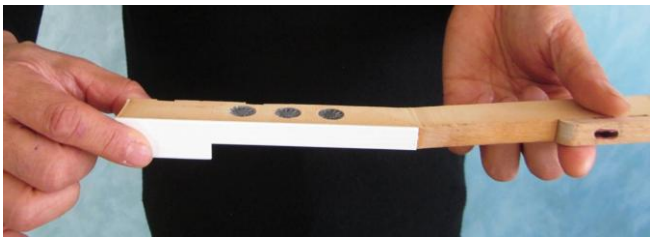
Let participants to try with actual key sticks.

Compare the MoI of two keys

Which do you feel more resistance when moving?



Short & no lead
➢ upright



Long & some leads
➢ grand

By this way, finger feels purely MoI of the keys i.e. no gravity effect.

Experience MoI of a hammer

What do you feel when giving torque to the knuckle?

➢ **Resistance of rotation = MoI of the hammer**

Give force at the knuckle forward and backward quickly at parallel to the ground

Compare the MoI of two hammers

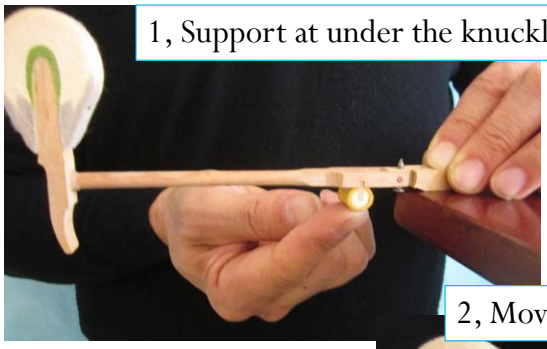
How do you feel? How quickly are they moving?

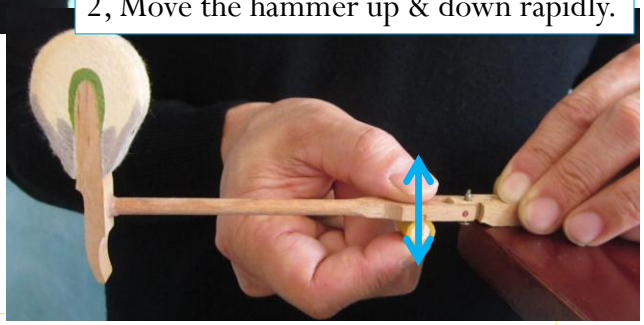
Treble hammer

Bass hammer

Finger should feel huge difference between two.

Hammers at vertical movement



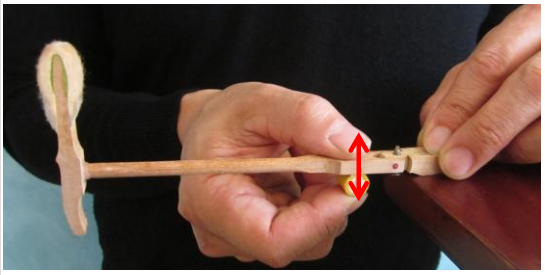
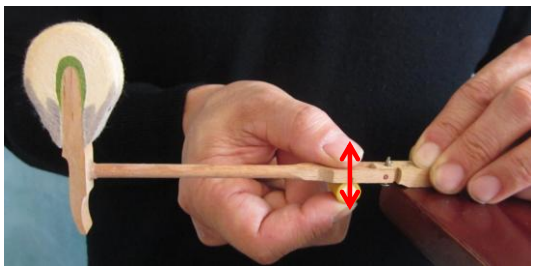


Need additional power to move it up

Left above 1 gives the force/torque towards to its BW. When moving like 2, resistance from MoI is added.

Bass vs. Treble

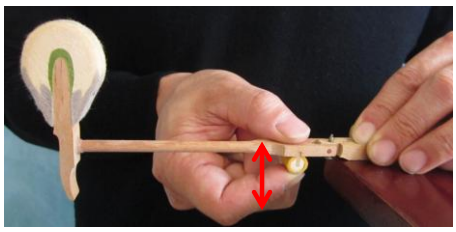
- Try tremolo at treble hammer and bass hammer.

Which do you feel heavy?

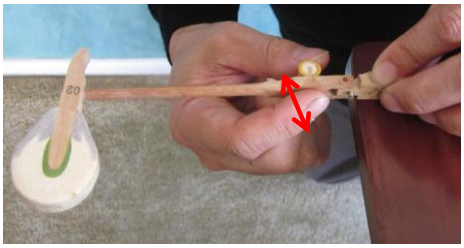
Easily achievable tremolo at treble hammer but bass hammer is hard to move so quickly because of much bigger MoI.

Effect of Gravity



Vertical movement

The MoI + Torque by gravity



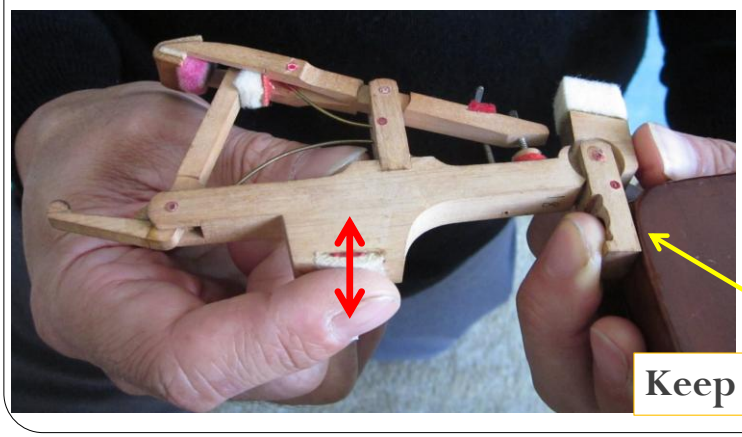
Horizontal movement

The MoI only

Experience MoI of a whippen

- Kinetic resistance of the whippen = MoI of the whippen

Move the whippen forward and backward quickly at parallel to the ground



Actual trial. Very easy to move.

Moment of Inertia

- Kinetic resistance of rotating object

Linked Moment of Inertia

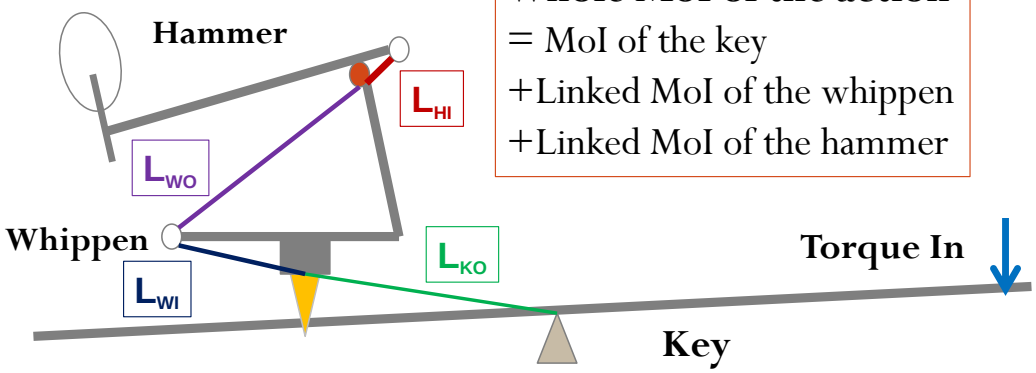
- The Moment of Inertia transferred through linked parts

Gear Ratio

- Output/input ratio of linked rotating parts

MoI of linked multi-connected parts needs to be calculated by theory.

Linked Moment of Inertia

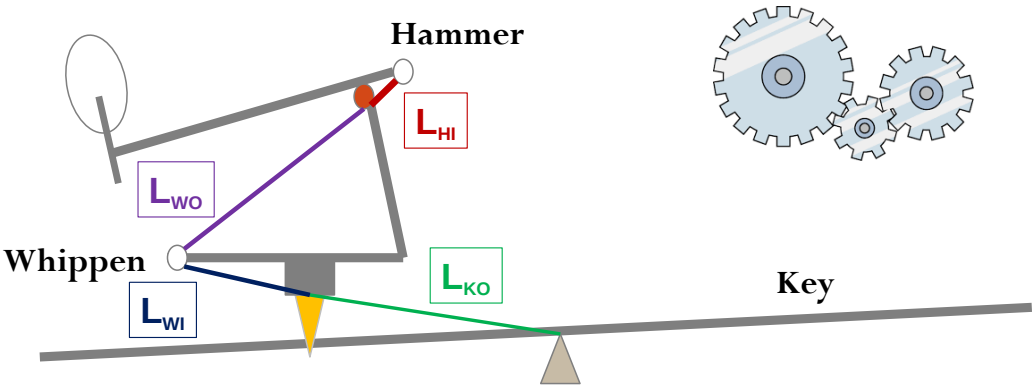


Whole MoI of the action
= MoI of the key
+Linked MoI of the whippen
+Linked MoI of the hammer

$$\text{MoI}_{\text{(Whole action at key)}} = \text{MoI}_{(K)} + \text{MoI}_{(W)} \times (L_{KO} / L_{WI})^2 + \text{MoI}_{(H)} \times (L_{WO} / L_{HI} \times L_{KO} / L_{WI})^2$$

Gear ratio can be calculated by their output/input distances.

Gear Ratios



Gear ratio (K to W) $= L_{KO} / L_{WI}$

Gear ratio (K to H) $= L_{WO} / L_{HI} \times L_{KO} / L_{WI}$

Change pivot point of the key

❖ **At front side = LKO bigger**

Bigger gear ratio
= Bigger MoI

❖ **At back side = LKO smaller**

Smaller gear ratio
= Smaller MoI

My action model has movable pivot point of the key which doesn't move for-aft position of the key itself.

Sample figure by changing pivot position at the key

➢ Gear ratio: Pivot at front side 9.8, at back side 9.3
(Squared figures are ９５．６、８５．９)

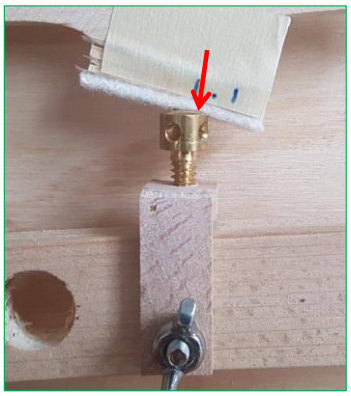
Pivot at front side (4 mm from center)
１６１，０００ (increased by ４%)

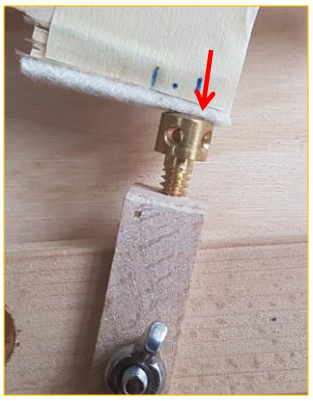
Pivot at back side (4 mm from center)
１４８，０００ (decreased by ４%)

(Pivot at center: 154,000)

Calculation from the action model

Change connection point at capstan - heel





❖ **At back side =**
L_{KO} bigger & L_{WI} smaller

Bigger gear ratio
= Bigger MoI

❖ **At front side =**
L_{KO} smaller & L_{WI} bigger

Smaller gear ratio
= Smaller MoI

Movable capstan position gives quick comparing between two extreme for-aft positioning.

Sample figure by changing connection point

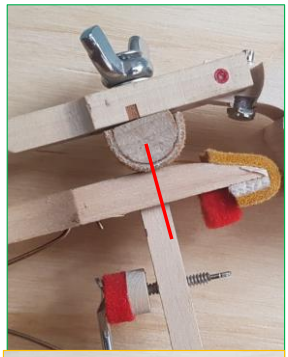
➢ Gear Ratio: Front side ８．８、Backside１０．３
Squared figures are: Front side７６．８、Back side１０６．１）

Connection at front side
１６９，０００（decreased by ４%）

Connection at back side
１８５，９００（Increased by ４%）

(Connection at center: 154,000)

Change roller position



❖ **Roller at forward = L_{HI} smaller**

Bigger gear ratio
= Bigger MoI

❖ **Roller at backward = L_{HI} bigger**

Smaller gear ratio
= Smaller MoI

Sample figures at different roller position

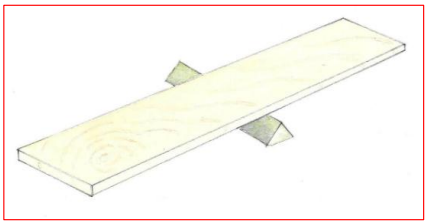
➢ Gear Ratio: Forward １０．１、Backward ８．６
(Squared figures are: Frontward １０１．５、Backward ７４．０)

Roller at 15.5 mm
１６８，０００（Increase by ９%）

Roller at 19 mm
１３３，０００（Decreased by １４%）

(Roller at 17 mm: 154,000)

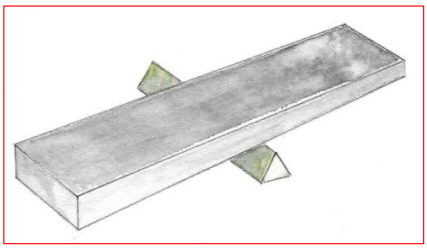
How pianists feel the MoI



❖ **Lighter Action: Smaller MoI**

→ Powerful pianist feels lack of resistance

→ Less power pianist feels controllable



❖ **Heavier Action: Bigger MoI**

→ Powerful pianist feels controllable

→ Less power pianist feels too heavy

Illustration represents two types of actions which have different MoI level.

Balance between playing force and MoI

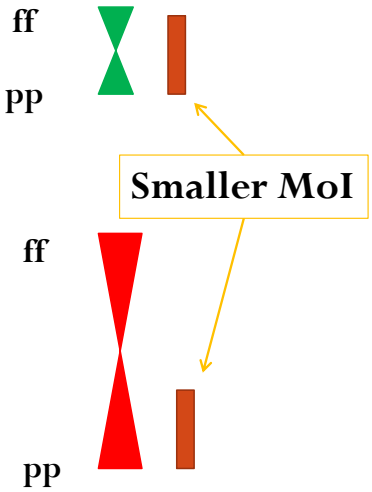
Play at lighter action with smaller MoI

The pianist who has narrow band of playing force:

Feels controllable and expressive

The pianist who has wider band of playing force:

Feels limited volume and expression



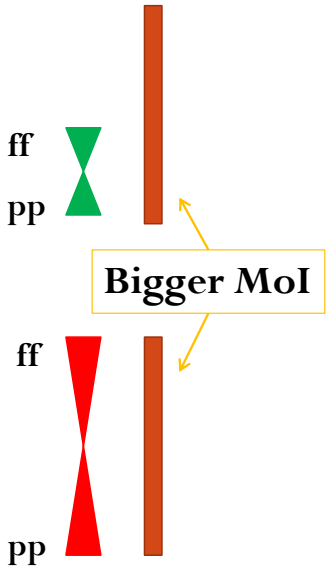
Explaining how two different pianists could control the action which has smaller MoI.

Balance between playing force and MoI

Play at heavier action with bigger MoI

The pianist who has narrow band of playing force:

Feels too heavy



The pianist who has wider band of playing force:

Feels controllable and expressive

Decide Strike Weight level

- Lighter hammer has better tremolo ability
- Heavier hammer has deeper and bigger tone

➡ **Find desirede SW**

- **with given Strike Ratio**
- **between touchweight and tonal quality**

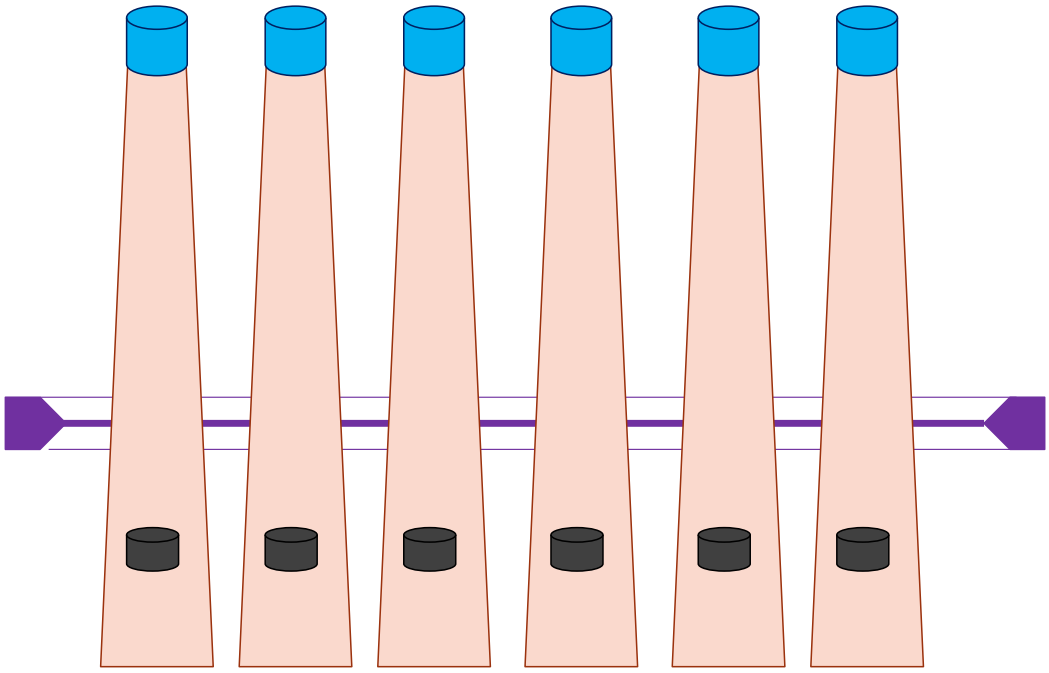
- Using Smart chart gives better alignment of tone and touch
- Given hammer set has limited band of adjusting weight

How we can approach to each touchweight component, SW

Set up Front Weight

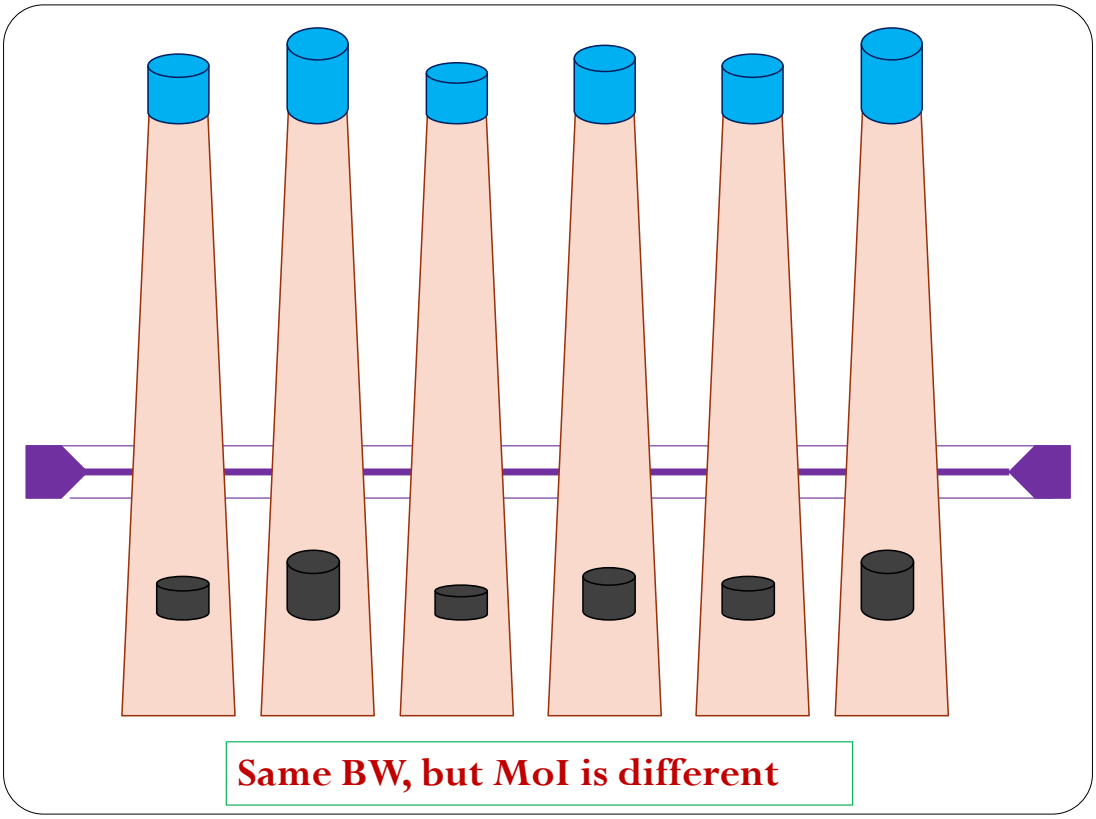
FW would be better set at least minus 3 grams from FW ceiling

Locate key leads according to the amount of MoI



Even SW, FW, BW, then MoI are even

All keys are moving similarly both statically and kinetically.



Showing importance of smoothed up SW and FW

Set up Ratios

- **5.4 to 5.8 of AR** for standard regulation
- **5.5 to 6.0 of SR** for reasonable static touchweight
- **Gear ratio is related with AR & SR**

Indicating recommended ratio range

Sample set up (1)

Small ~ moderate grand with existing parts:
Requested lighter touch & good repetition

- Adjust SW lighter side
- Lower SR to 5.5 ~6.0
- FW is set minus 3 grams from ceiling
- Relocate key leads to balance pin side
- Adjust BW to 36 ~ 38 grams

Sample setting model

Sample set up (2)

Small ~ moderate grand with existing parts:
Requested heavier touch & keep good repetition

- Adjust SW lighter
- Set Higher SR to 6.0 ~6.5
- Set FW at least minus 3 grams from ceiling
- Relocate key leads to mass center of around center
- Adjust BW to 40 ~ 45 grams

Another sample setting

Adjust SW lighter side to get good tremolo but giving higher SR & BW to get heavier feeling.

Sample set up (3)

Concert grand:
Standard touch and good repetition ability

- Smooth SW around #9 ~ #10
- 5.5 ~ 6.0 of Strike ratio
- Set FW minus 3 grams from ceiling
- Locate key leads to inner side
- 40 g ~ 42 g of BW
  or tapered BW (45 g :lower bass, 42g: upper bass,
  40 g: tenor and 38 g: treble etc.)

Very difficult to get good touch at concert grand due to naturally higher MoI level by bigger gear ratio and importance of its power i.e. required relatively heavier hammer.