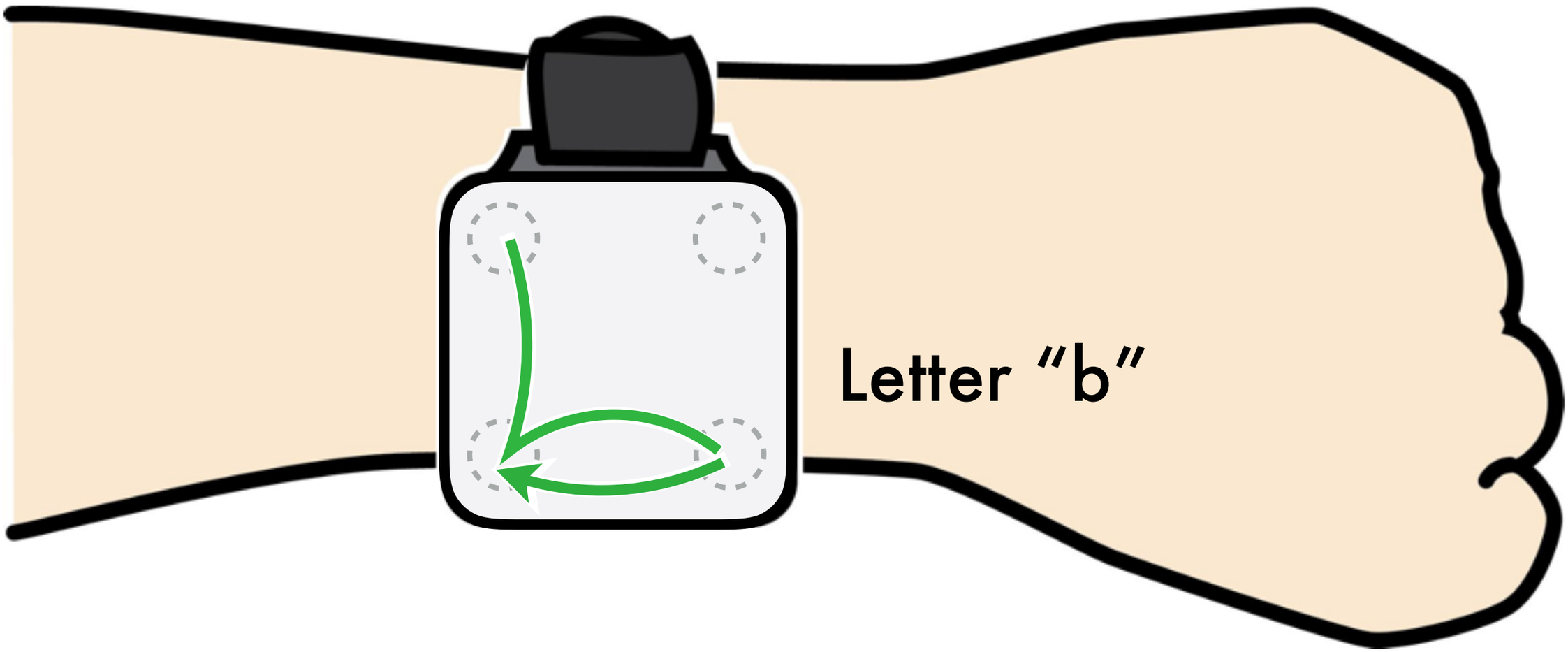
EdgeVib

effective alphanumeric character output using a wrist-worn tactile display

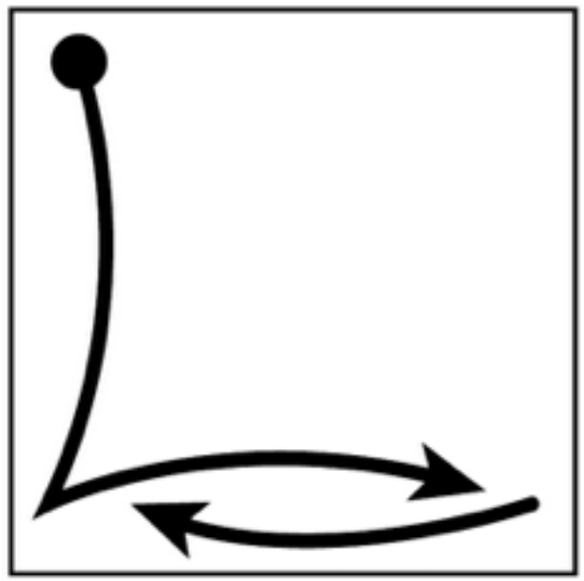


Yi-Chi Liao, Yi-Ling Chen, Jo-Yu Lo, Rong-Hao Liang, Liwei Chan, Bing-Yu Chen

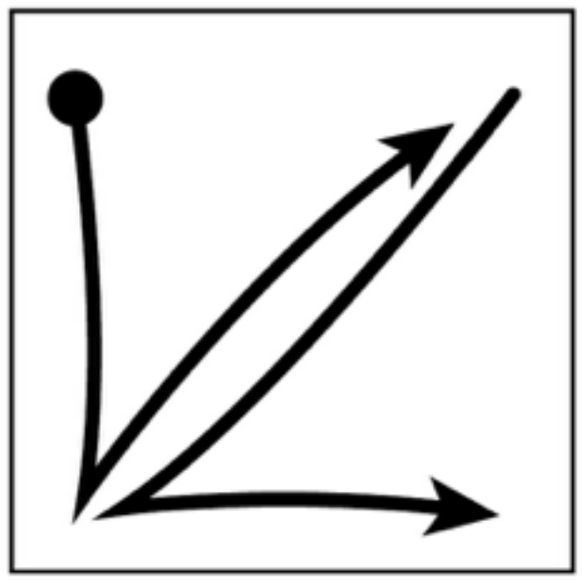
alphanumerical communications on a **wrist-worn tactile display** which is only a **2x2 vibrotactile array**

multistroke EdgeWrite [Wobbrock, UIST'03] patterns

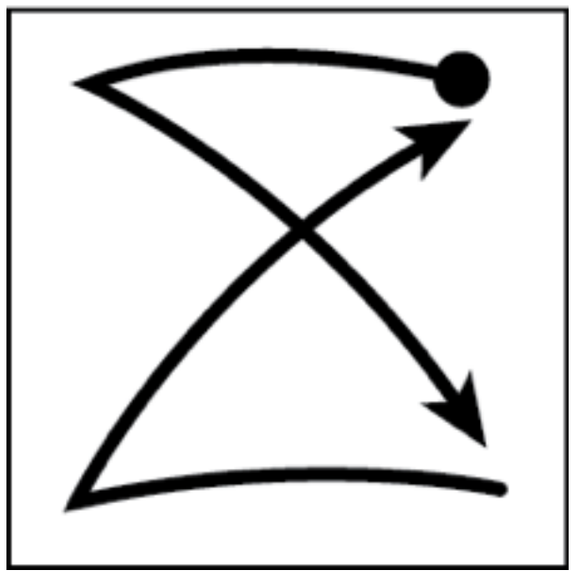
Letter "b"



Letter "k"

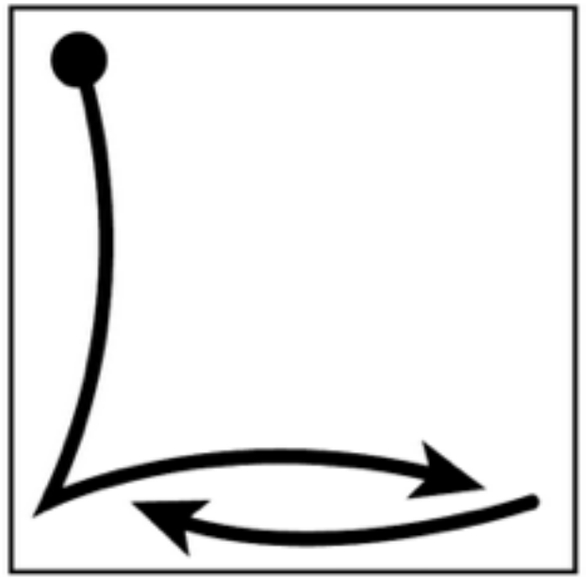


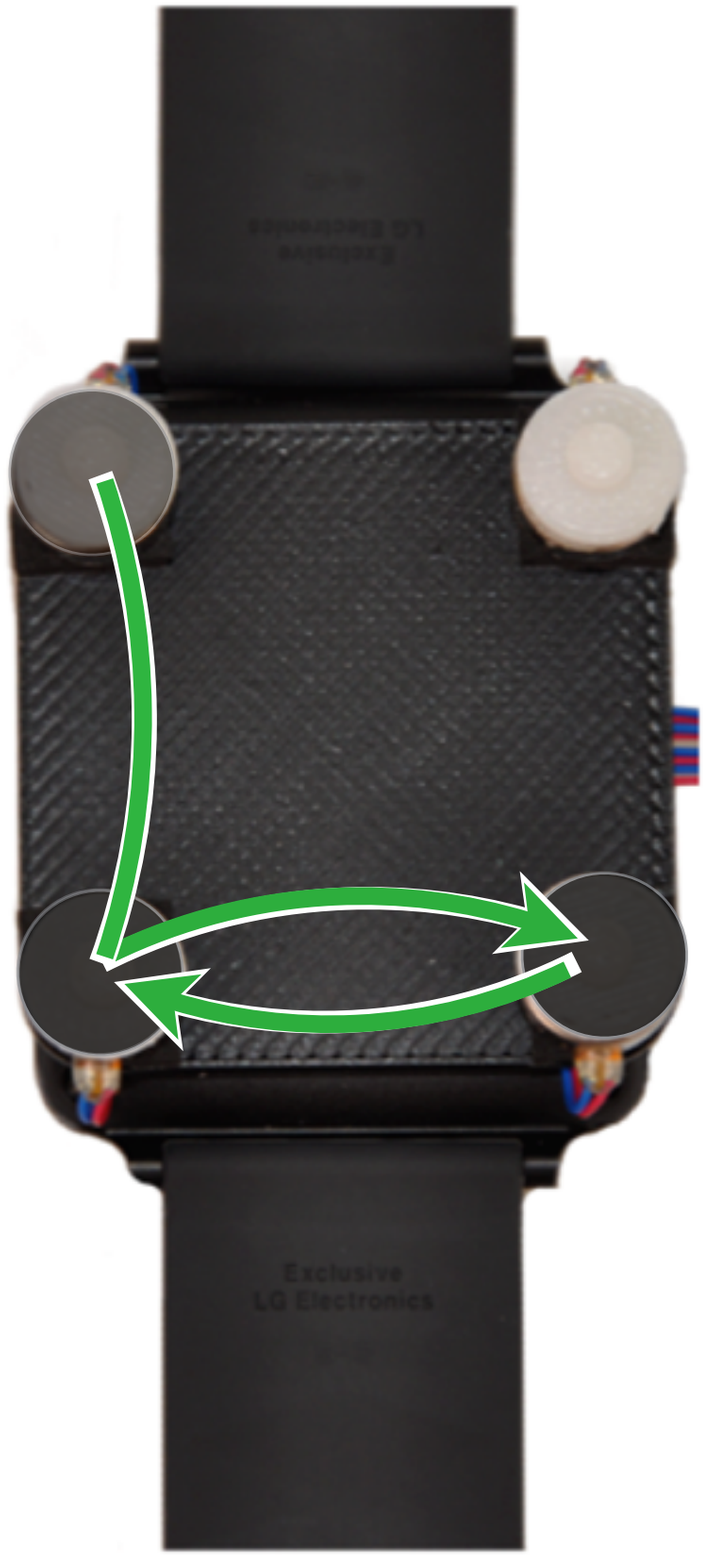
Digit "8"



alphanumerical communications on a **wrist-worn tactile display** which is only a **2x2 vibrotactile array**

Letter “b”

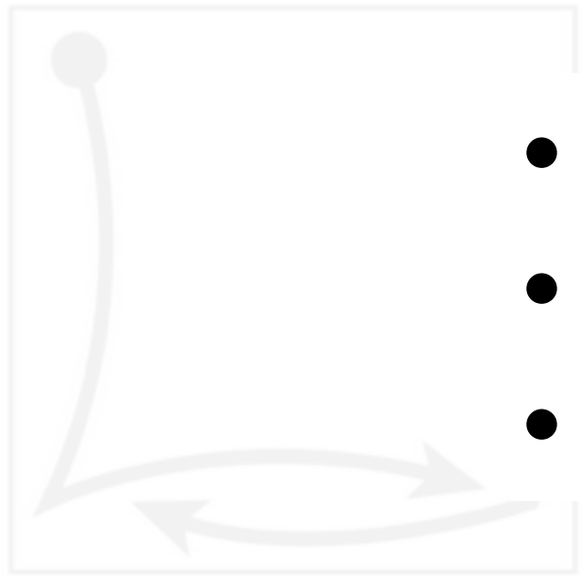




3-vibration stroke

+

2-vibration stroke



- easy-to-learn
- expressive
- reliable recognition rates

Introduction

in contact with user’s skin

how to deliver expressive messages through haptic channel?

in contact with user’s skin

single vibrator

vibrotactile arrays

[LEE, CHI ’15]

[LEE, CHI EA’09]

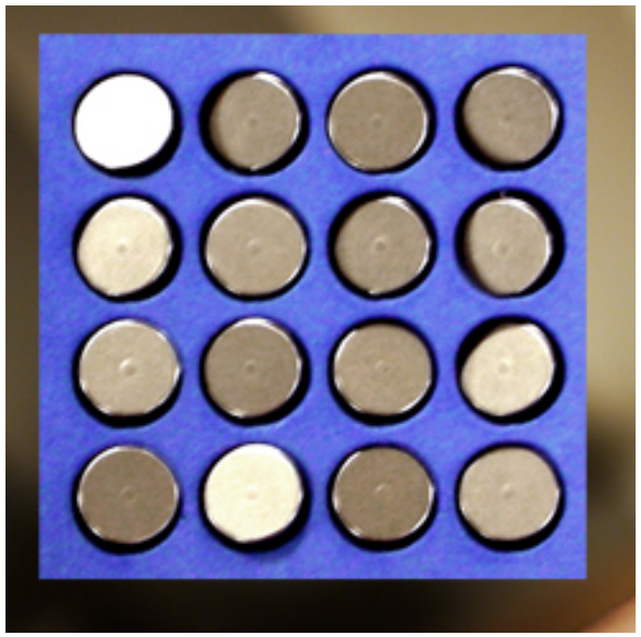
skin drag displays

[Bark, HAPTICS’08]

[Ion,CHI’15]

single vibrator

vibrotactile arrays



[LEE, CHI EA'09]

[LEE, CHI '15]

skin drag displays

[Bark, HAPTICS'08]

[Ion,CHI'15]

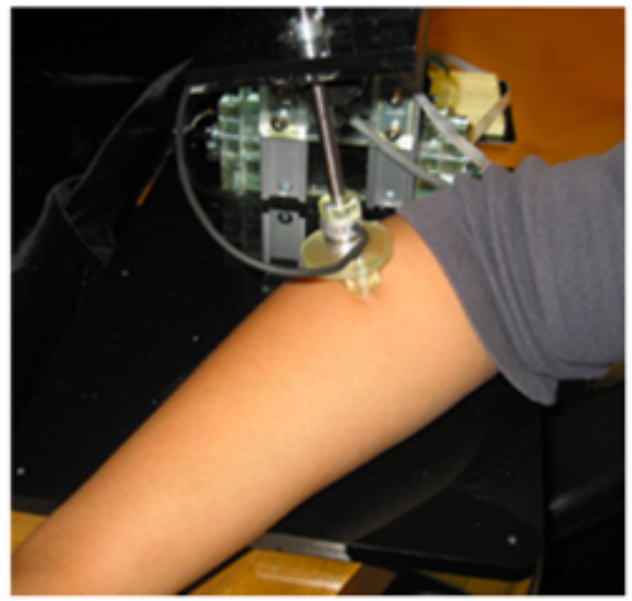
single vibrator

vibrotactile arrays

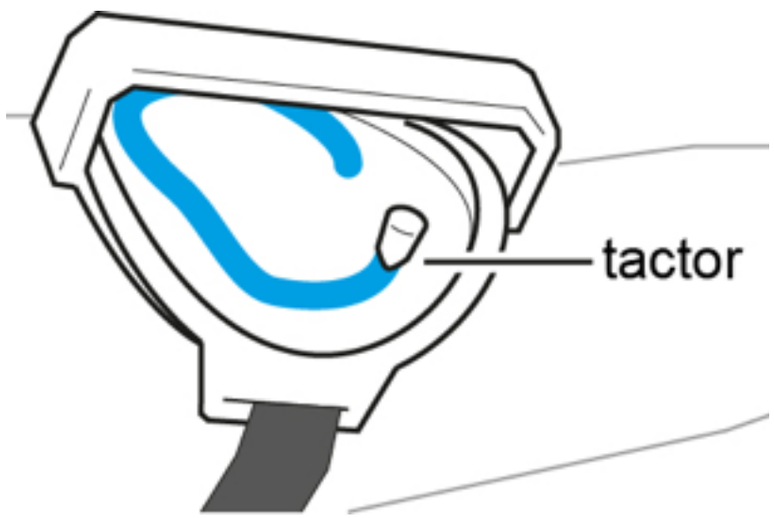
[LEE, CHI ’15]

[LEE, CHI EA’09]

skin drag displays



[Bark, HAPTICS’08]



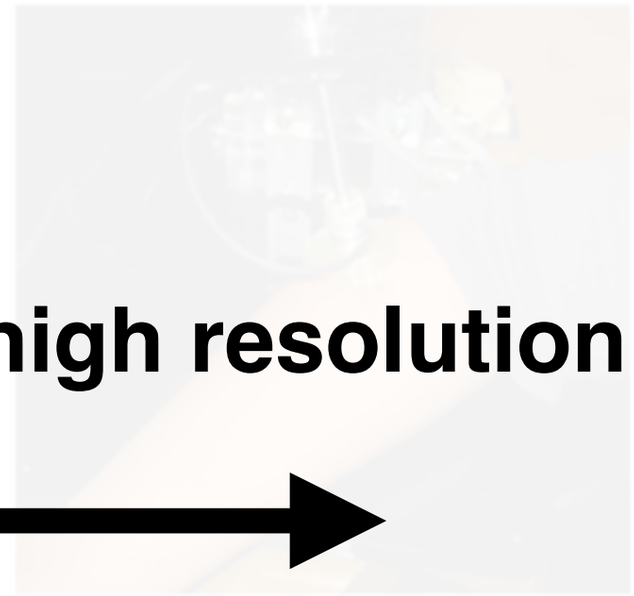
[Ion,CHI’15]

single vibrator | vibrotactile arrays | skin drag displays

low resolution

[LEE, CHI ’15]

[LEE, CHI EA’09]

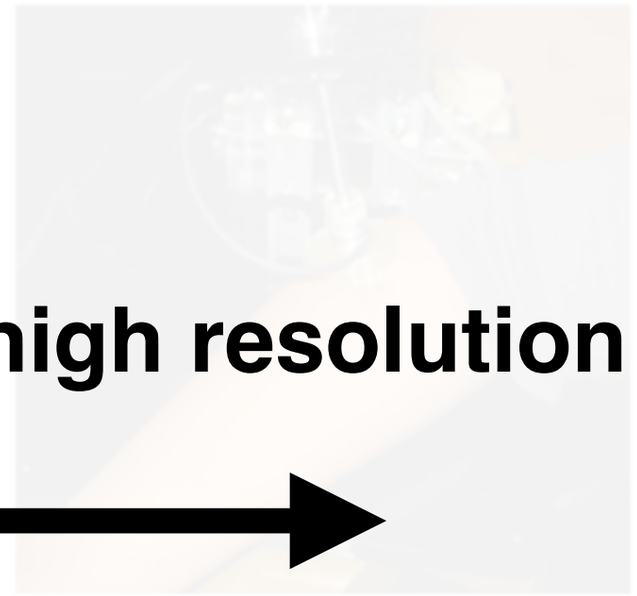


high resolution

[Bark, HAPTICS’08]

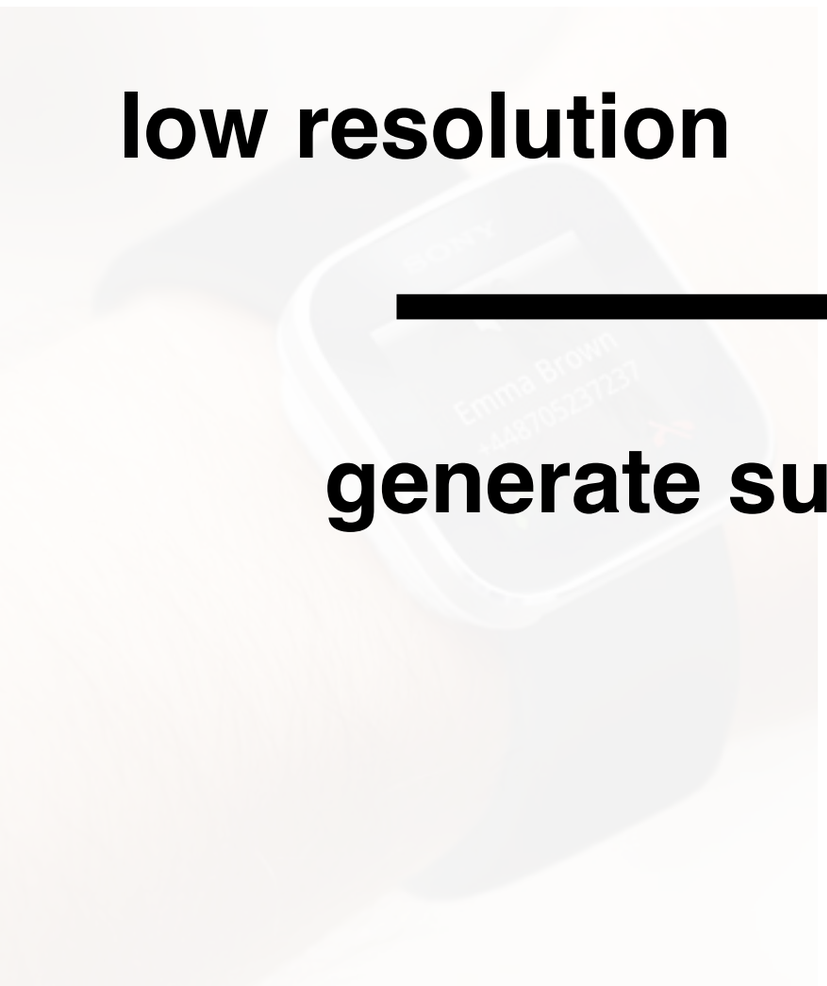
[Ion,CHI’15]

single vibrator | vibrotactile arrays | skin drag displays



low resolution

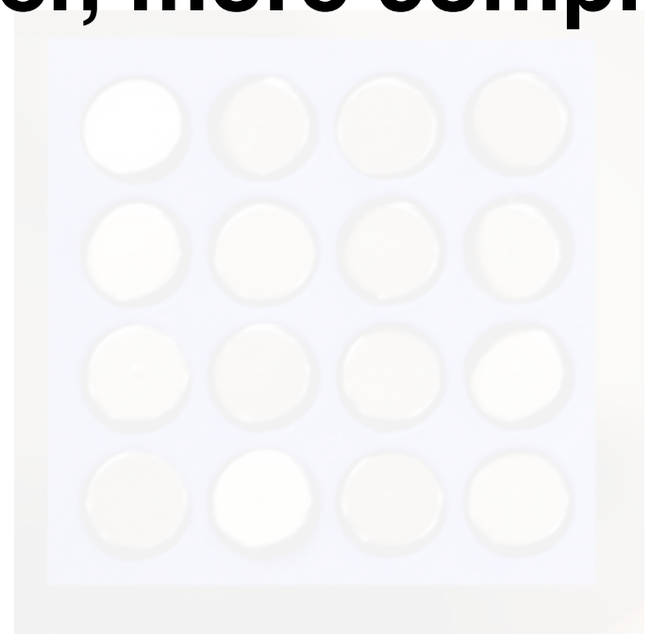
high resolution



[LEE, CHI'15]

[Bark, HAPTICS'08]

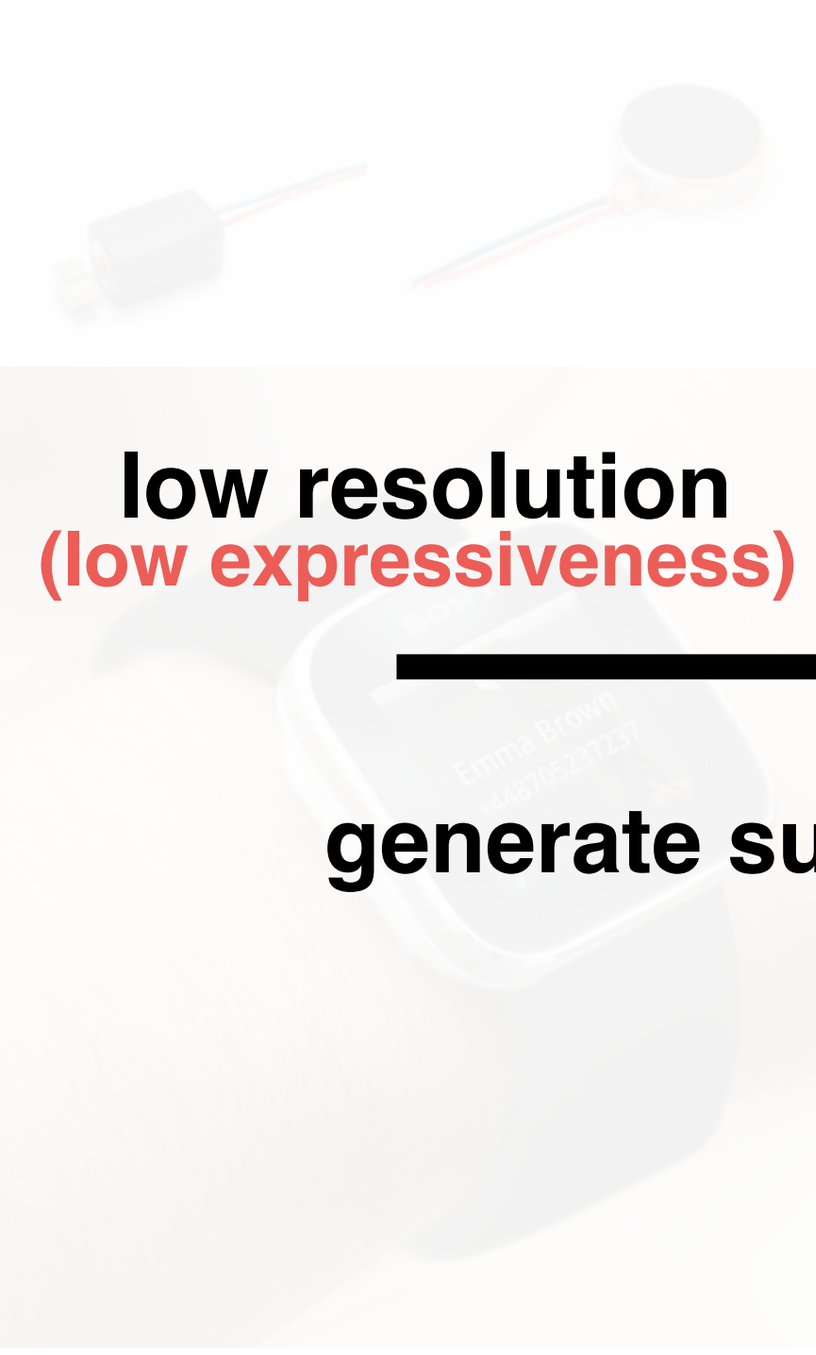
generate subtler, more complicated patterns



[LEE, CHI EA'09]

[Ion,CHI'15]

single vibrator | vibrotactile arrays | skin drag displays



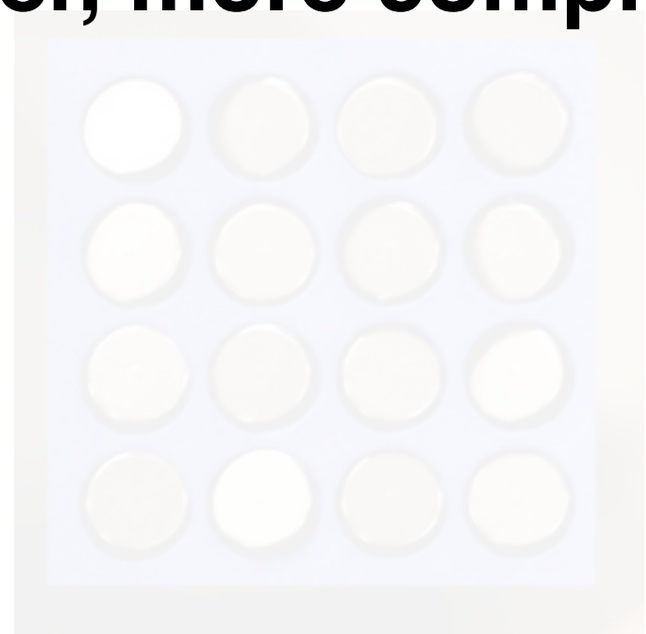
low resolution
(low expressiveness)

high resolution
(high expressiveness)

generate subtler, more complicated patterns

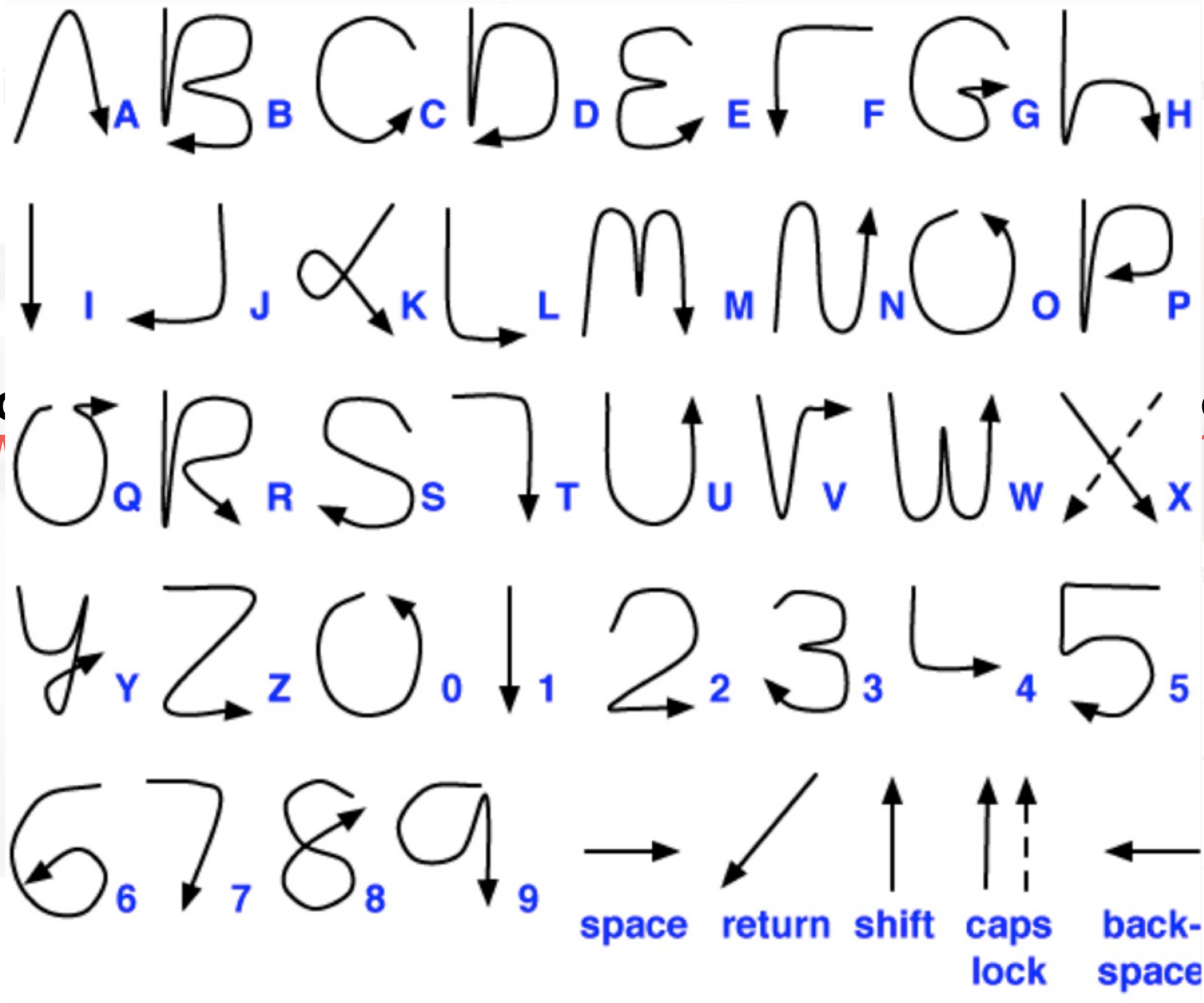
[LEE, CHI'15]

[Bark, HAPTICS'08]



[LEE, CHI EA'09]

[Ion,CHI'15]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6
7
8
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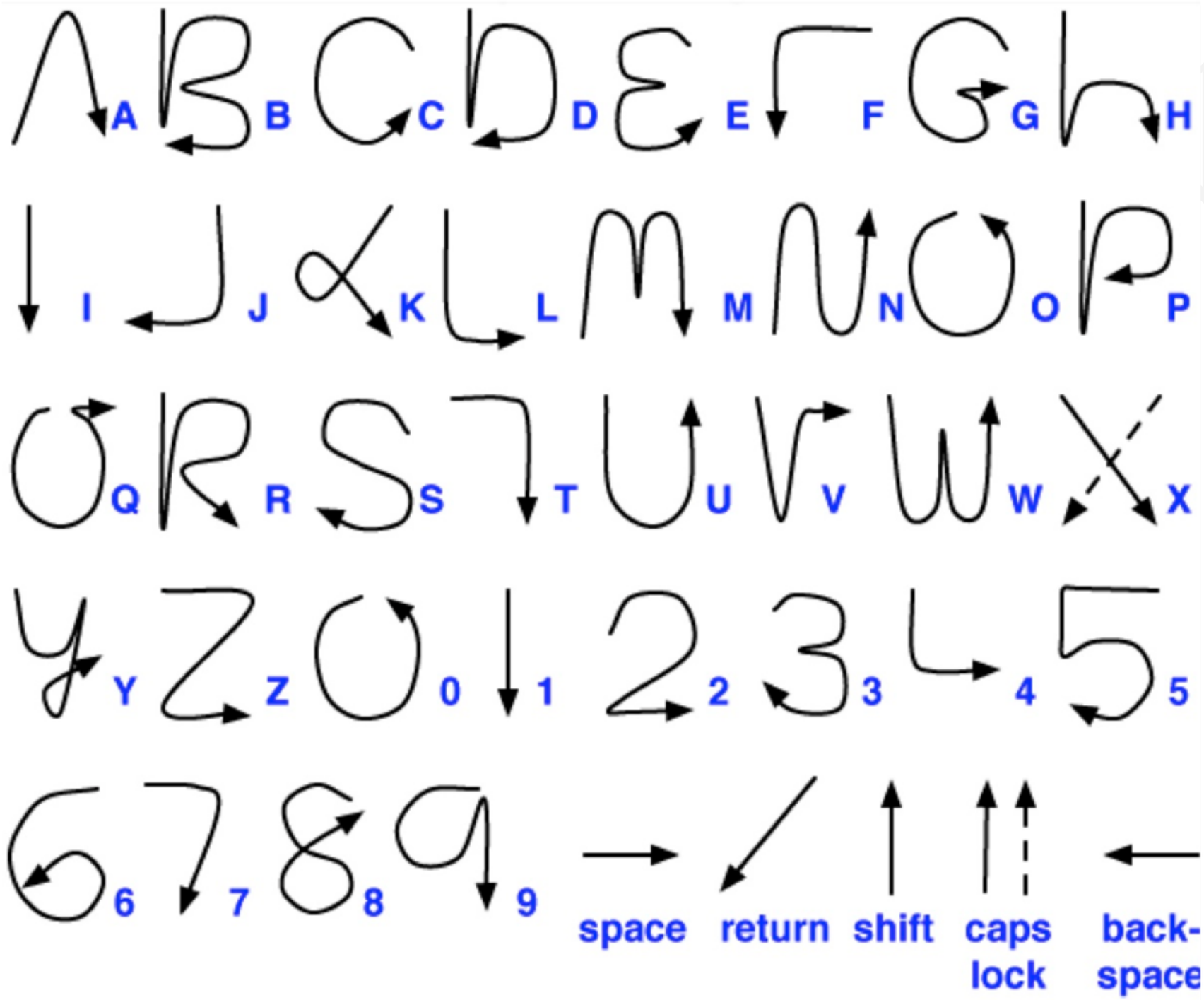
space
return
shift
caps lock
back-space

however,

the tactile perception of forearm is quite limited

[Ion,CHI'15]

skin drag display: **23.96% error**
vibrotactile array: **42.79% error**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4
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6
7
8
9
space
return
shift
caps lock
back-space

accuracy?

how to effectively display alphanumeric patterns on the wrist?

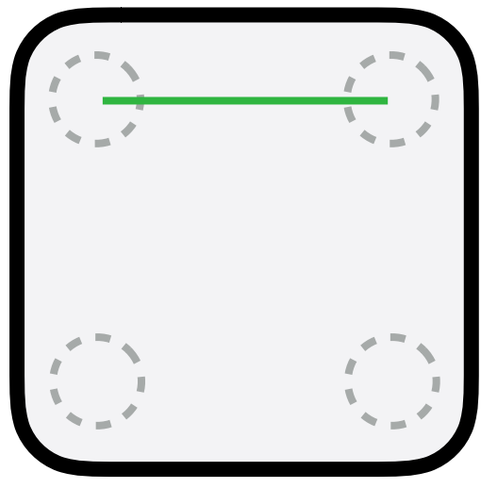
EdgeVib

a set of **multistroke** alphanumeric patterns on **low-resolution** array

3 user studies

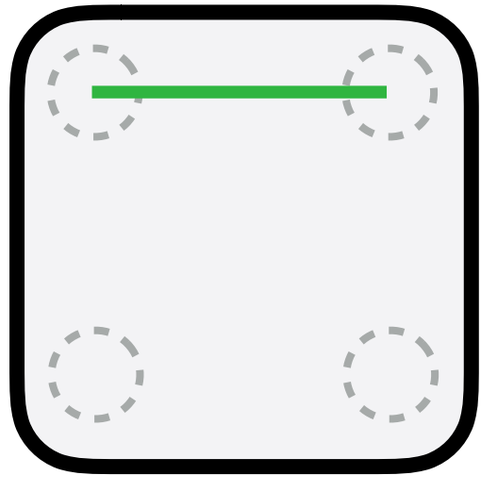
study 1::

optimal resolution:: **2x2**



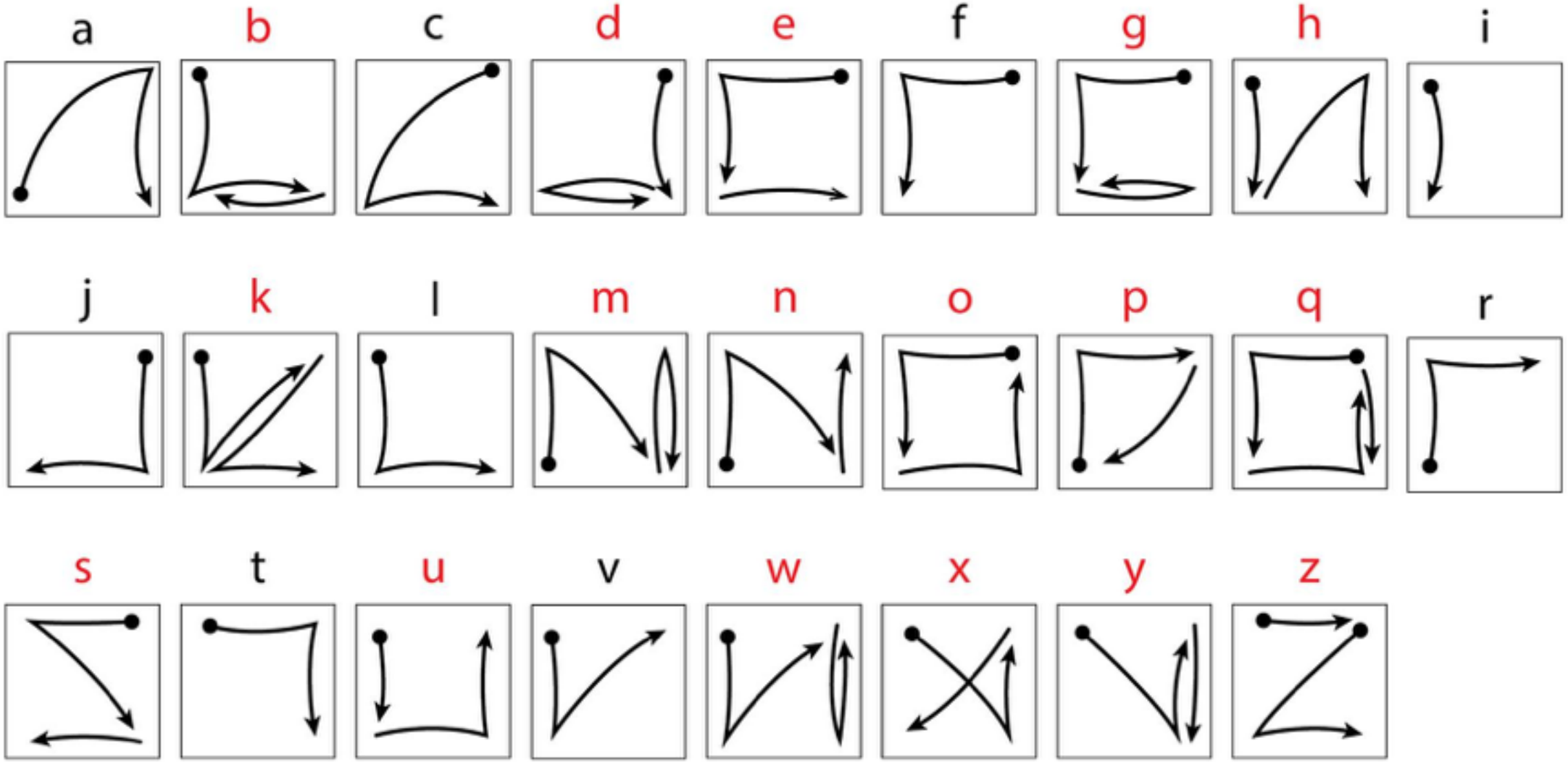
study 2::

recognizable length of EdgeWrite:: **3**



study 3::

optimal segmentation:: **3-vibration first**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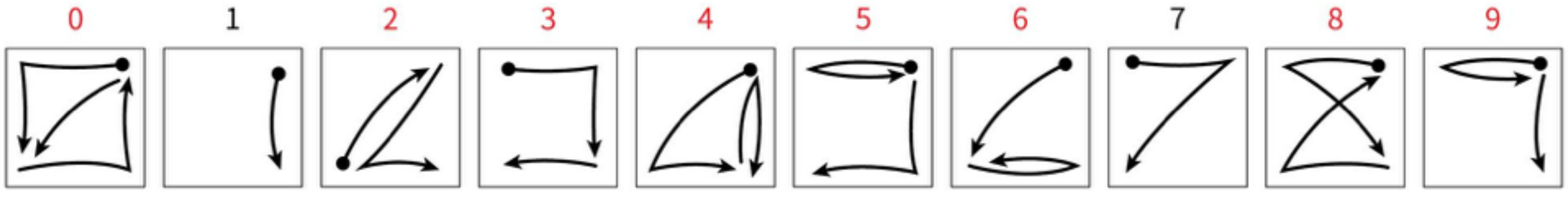
0
1
2
3
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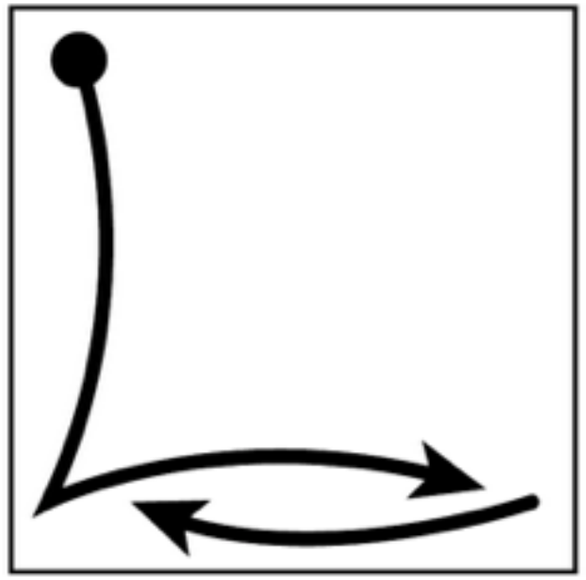
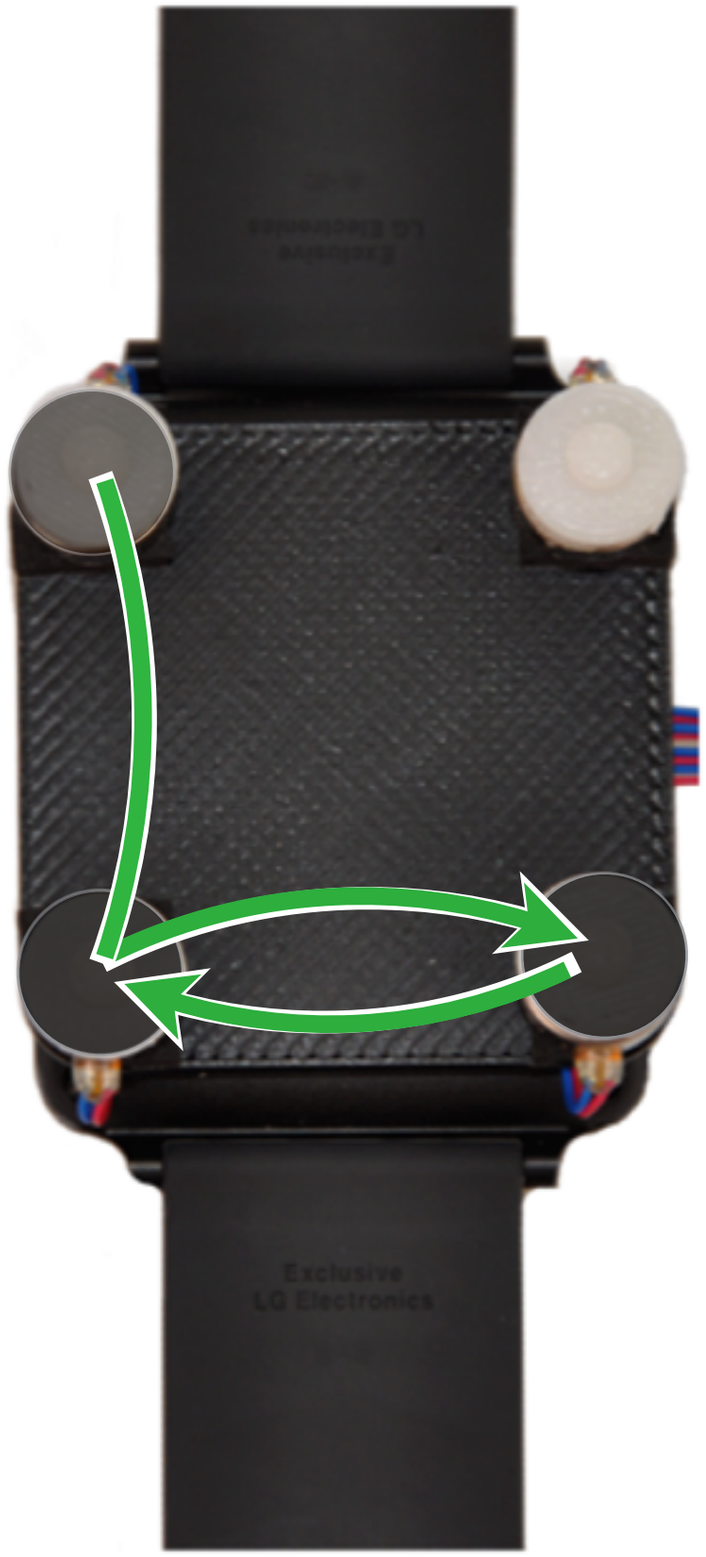
8
9

Letter “b”

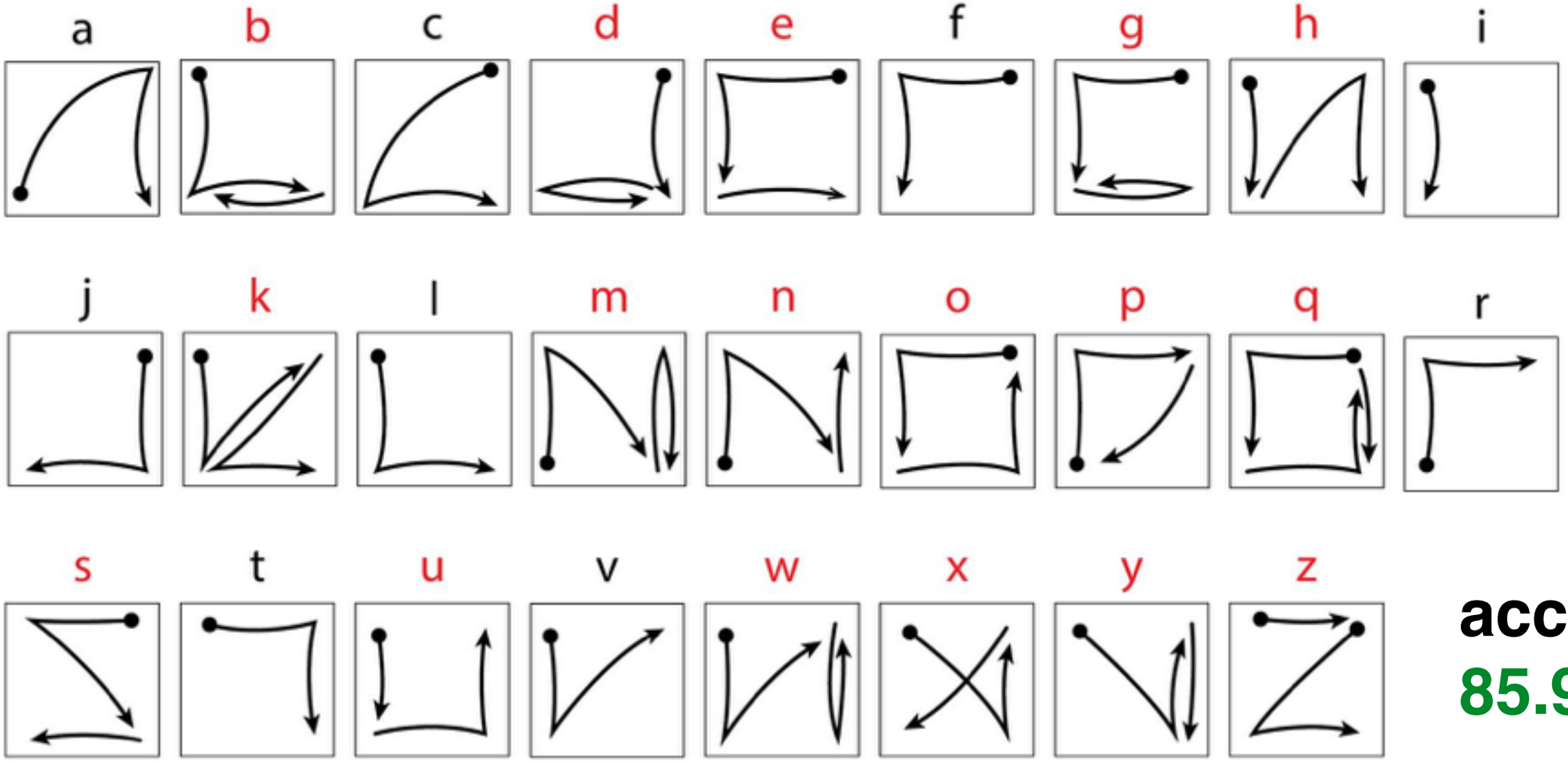




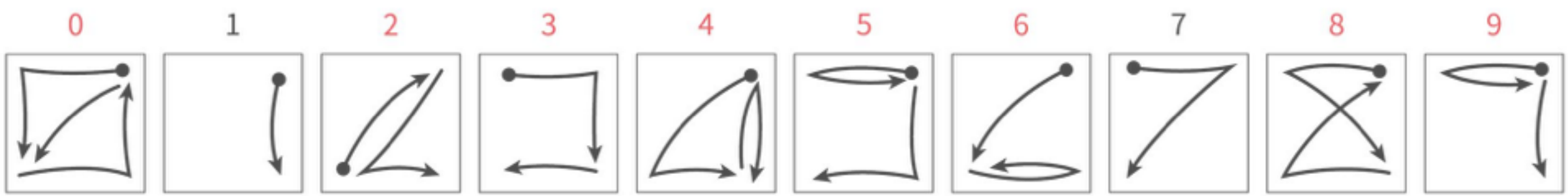
3-vibration stroke

+

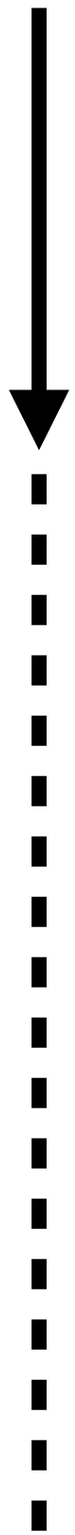
2-vibration stroke



accuracy:
85.9%



accuracy:
88.6%



Introduction

User Studies

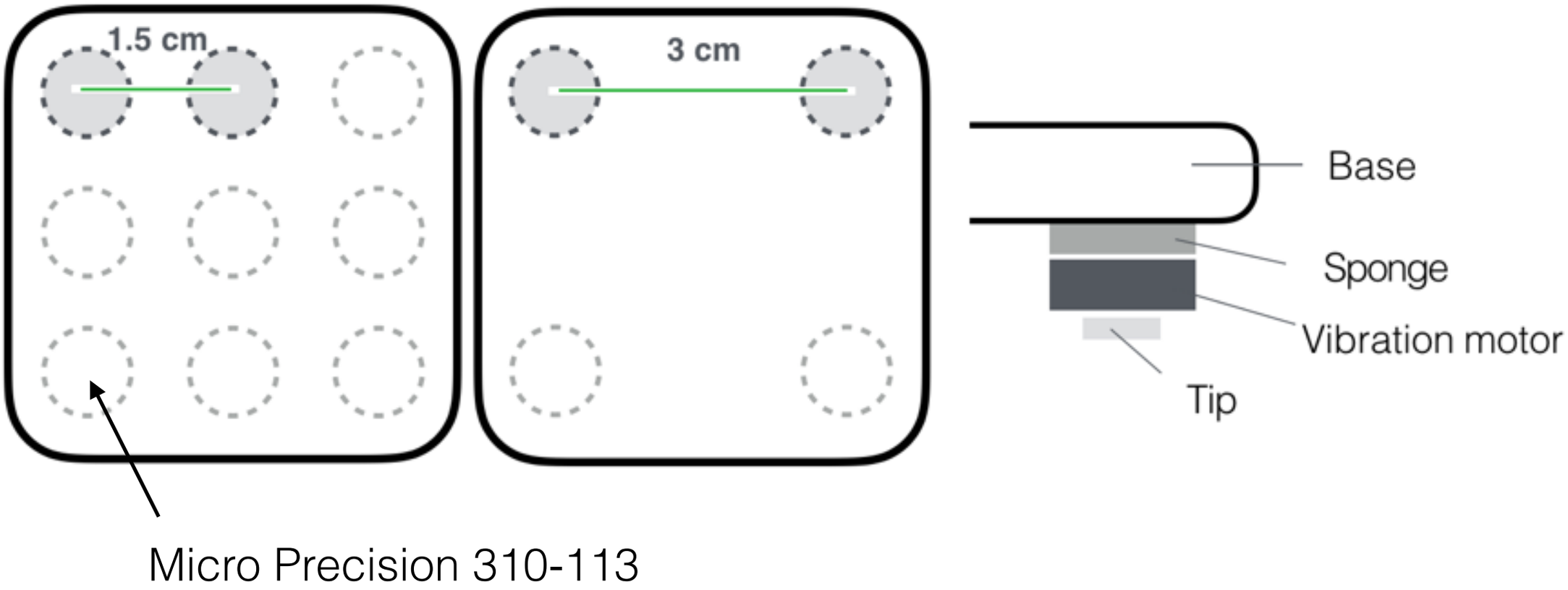
Design Principles

Evaluation

Discussion

Conclusion

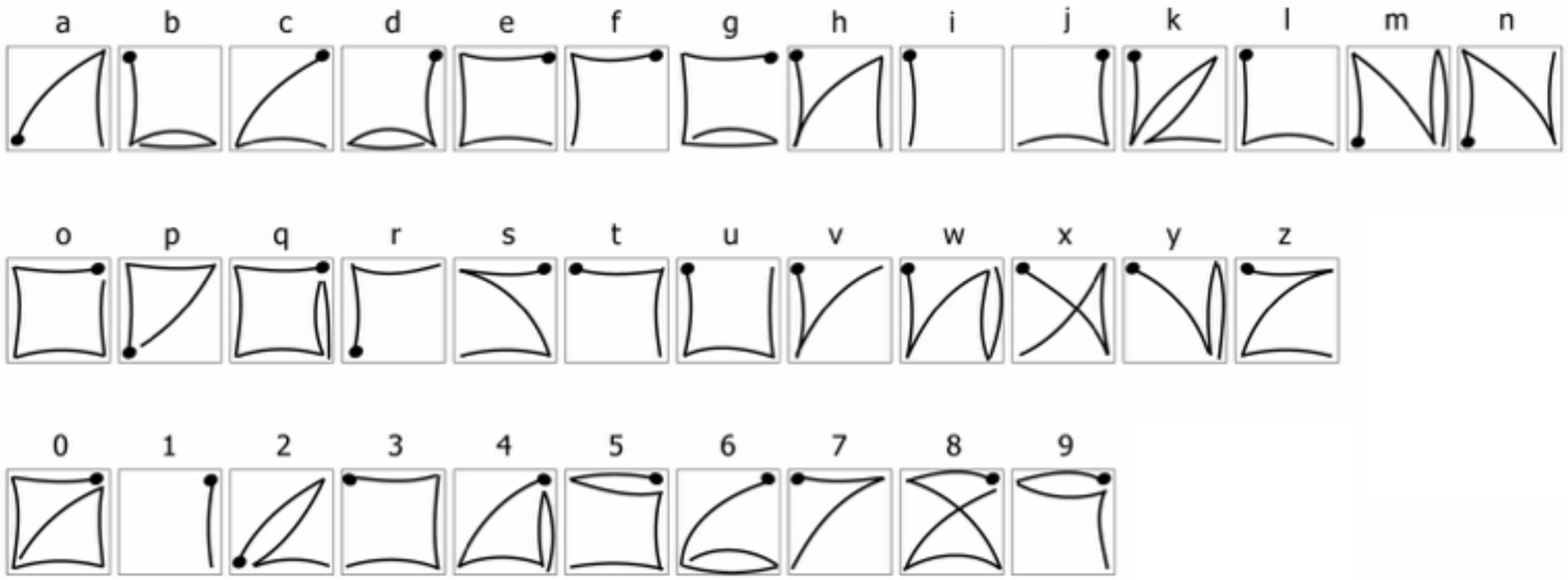
User Studies



500 ms vibration with 100 ms pulse

- right-handed participants, aged from 21 - 29
- identifying spatial patterns
- less than 60 mins

- learning phase
  - *learn the writing of EdgeWrite in 15 mins*



- training phase
  - *tactile training*
  - *participants could decide to replay patterns or not*

- testing phase
  - *actual study*

- learning phase
  - *learn the writing of EdgeWrite in 15 mins*

- training phase
  - *tactile training*
  - *participants could decide to replay patterns or not*

- testing phase
  - *actual study*

- learning phase
  - *learn the writing of EdgeWrite in 15 mins*

- training phase
  - *tactile training*
  - *participants could decide to replay patterns or not*

- testing phase
  - *actual study*

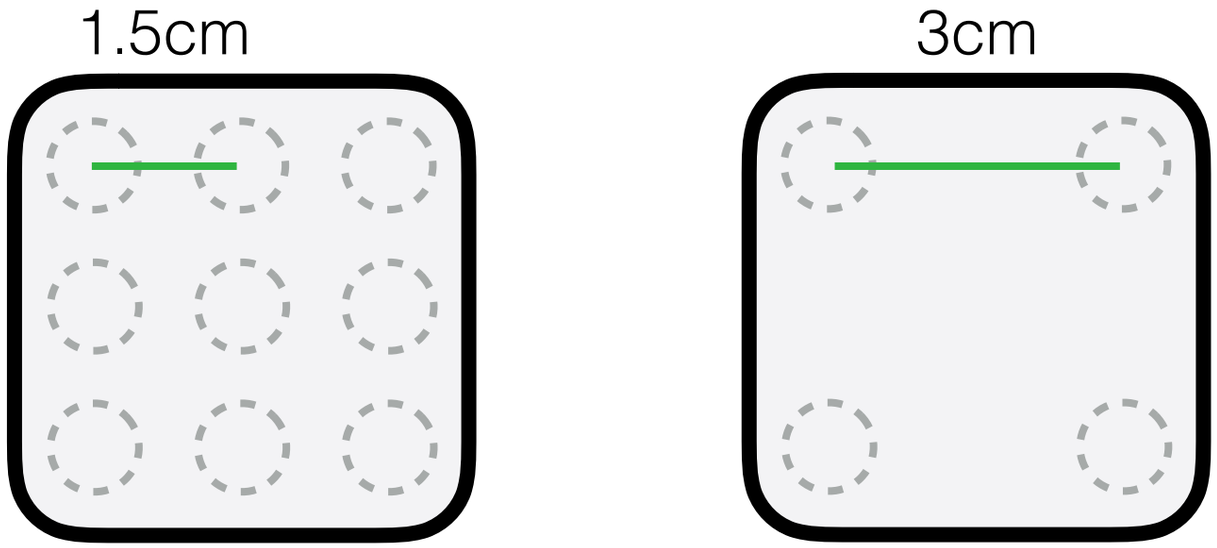
how to effectively display alphanumeric patterns on the wrist?

question::

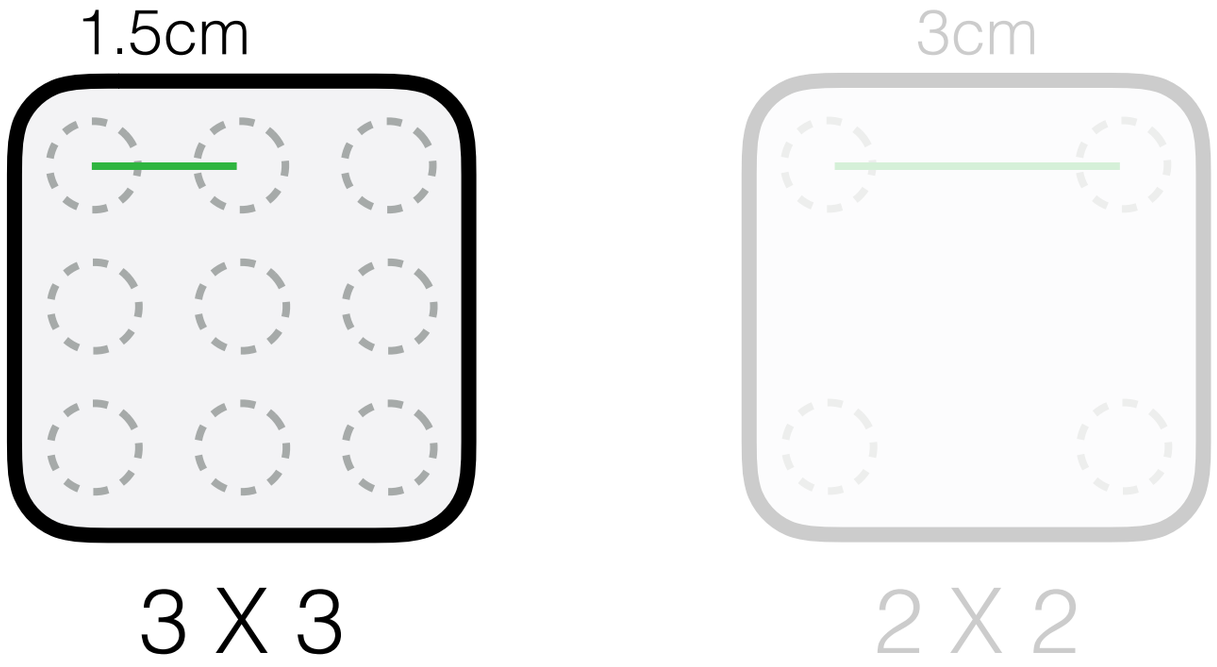
what is the optimal resolution of a wrist-worn tactile display?
does high-resolution have most effective performance?

#1

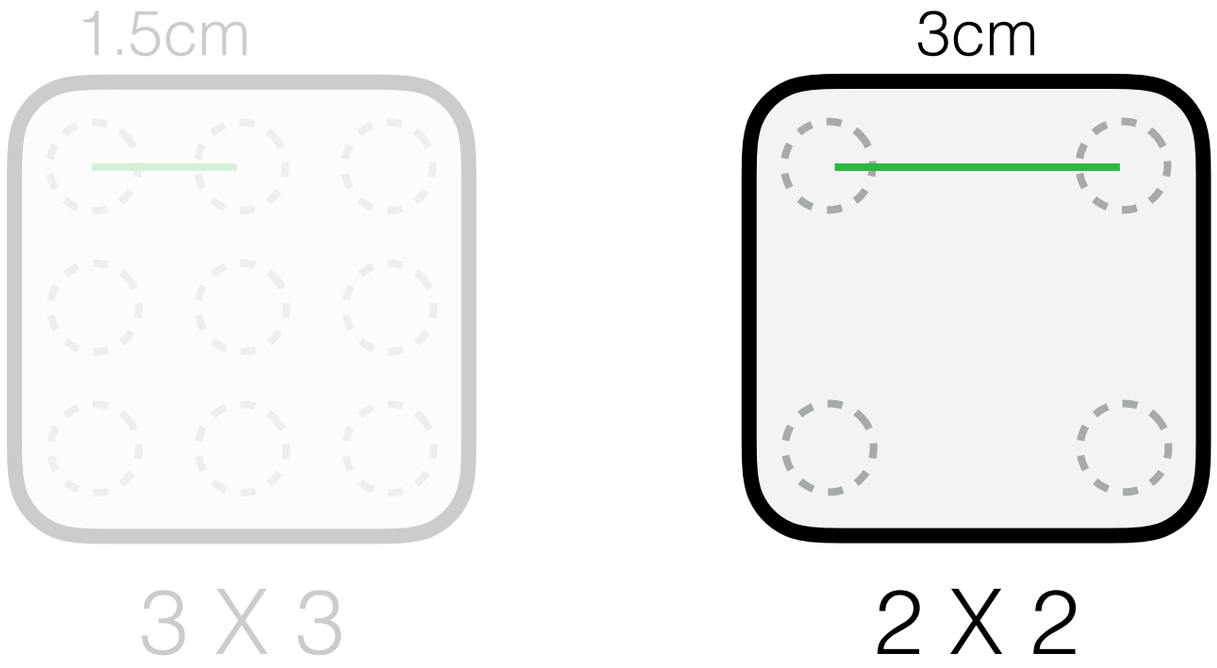
optimal resolution for vibrotactile wrist-worn tactile display



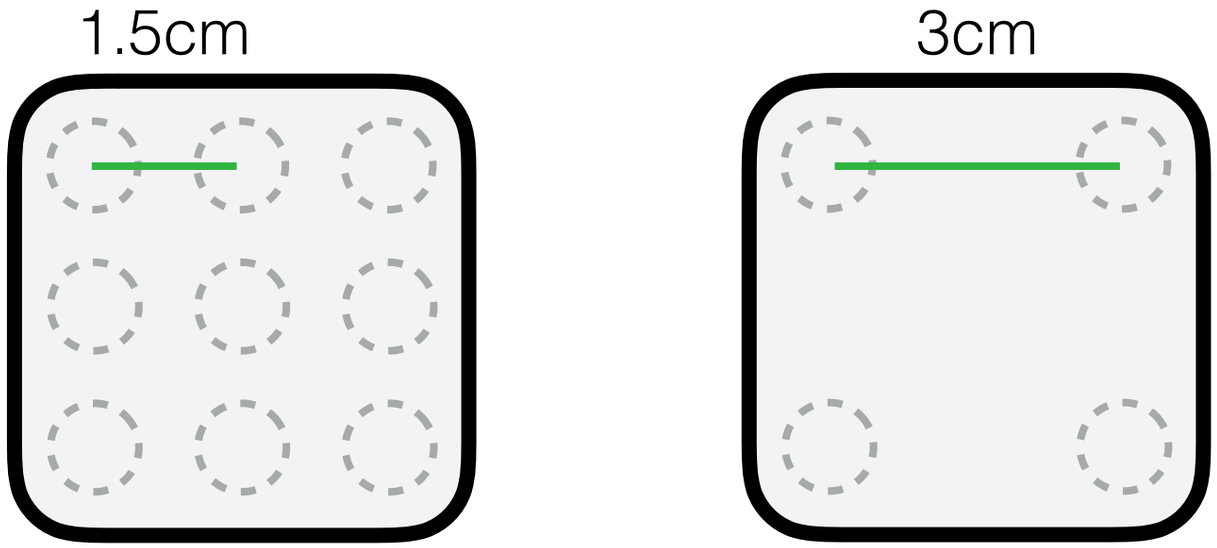
12 participants



12 participants



12 participants

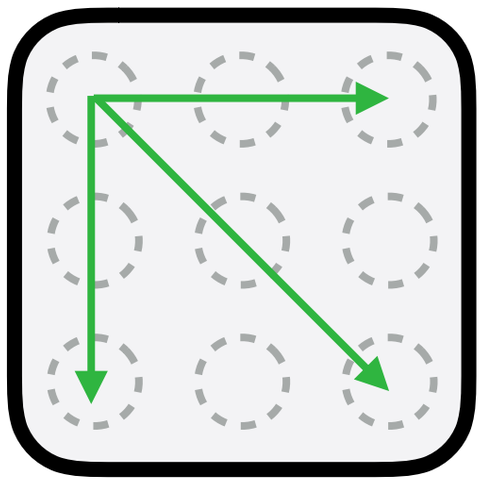


12 participants

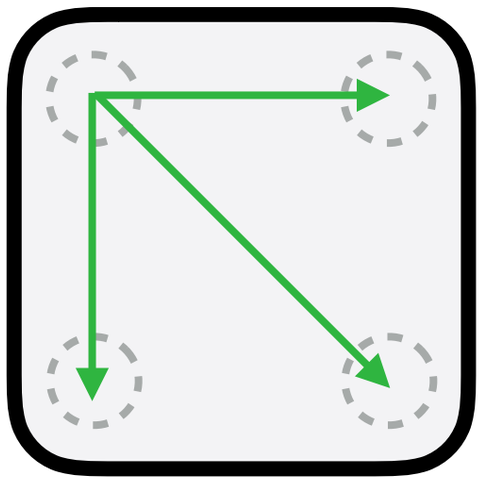
1.5cm

3cm

3 X 3

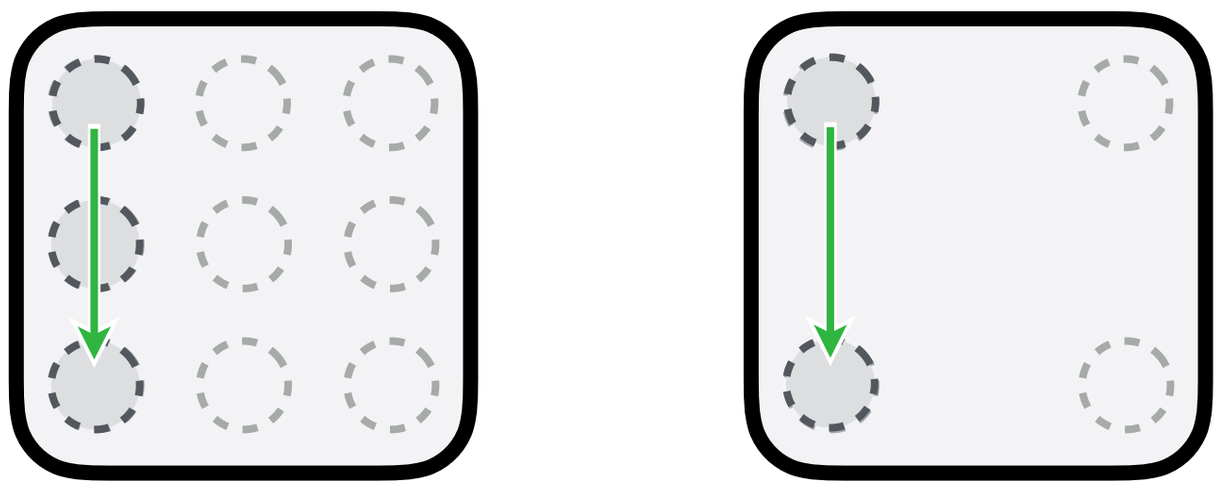


2 X 2



12 patterns x 5 rounds

significant difference ($p<0.05$)



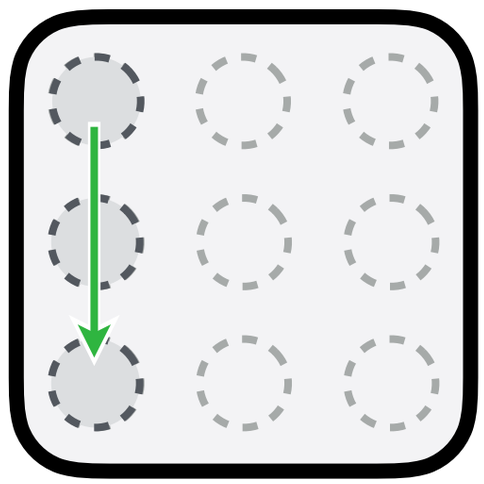
71%

79.3%

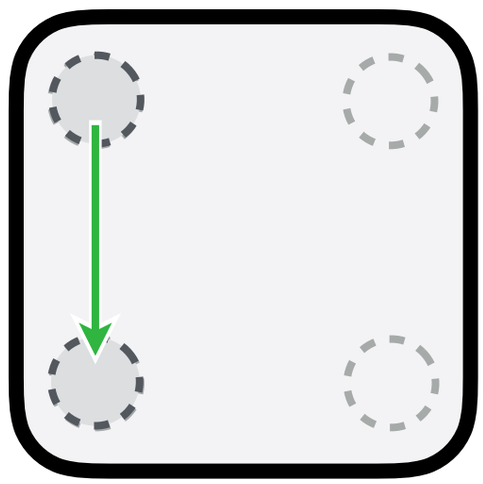
1.5cm

3cm

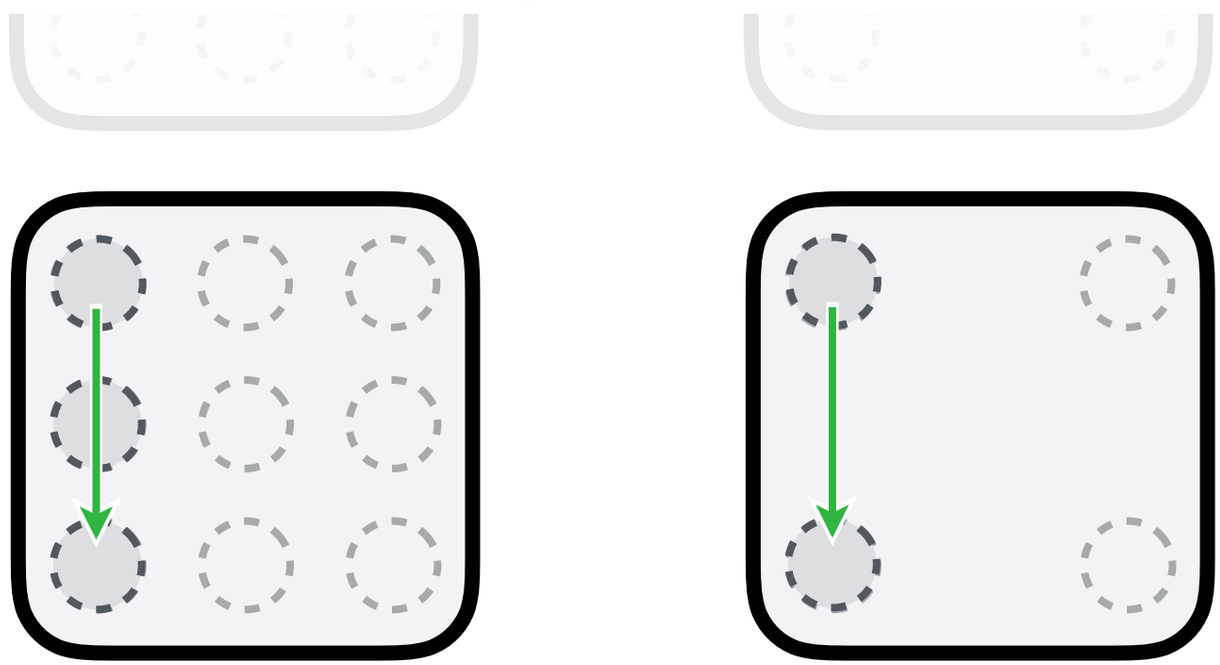
3 X 3



2 X 2

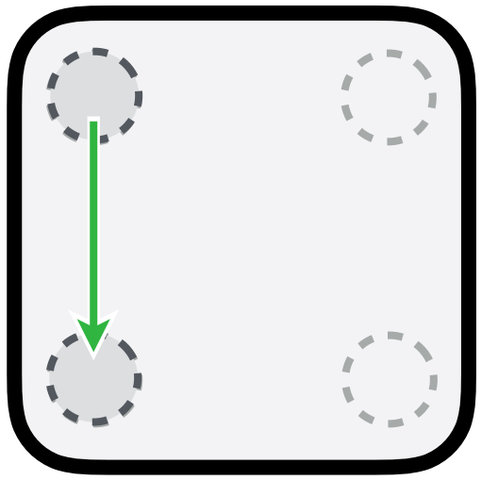


2x2 layout also outperforms in time efficiency

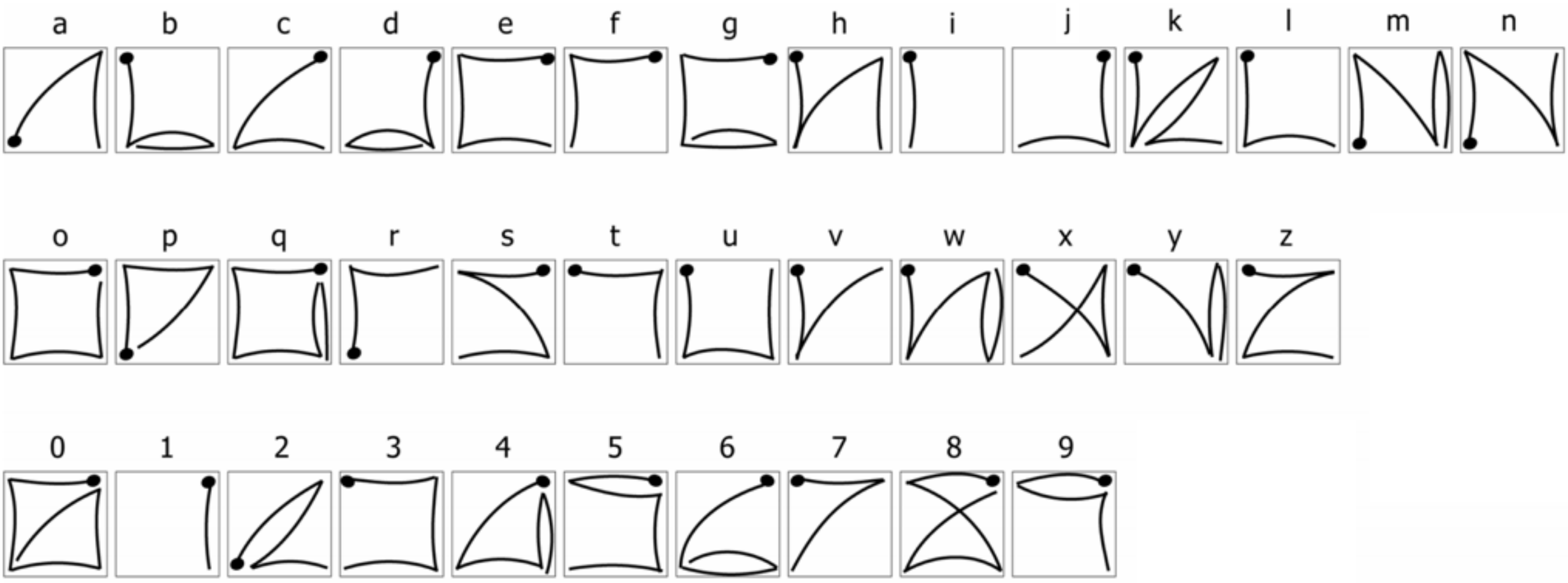


1.7 seconds

1.1 seconds



a 2x2 layout benefits in delivering
more recognizable patterns and better rendering efficiency



EdgeWrite [Wobbrock, UIST'03]

1. easy to learn (15 mins)

[Wobbrock, UIST'03]

1. easy to learn (15 mins)

2. can be perfectly applied to 2x2 configuration

[Wobbrock, UIST'03]

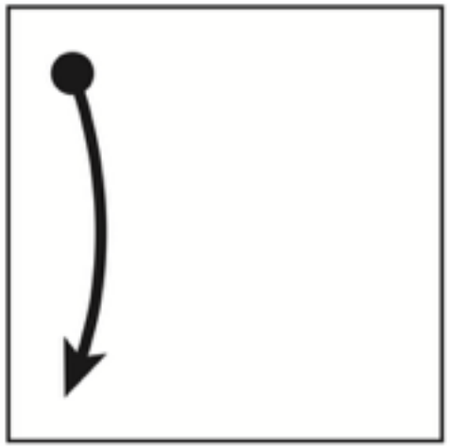
question::

does the length of patterns lead to different recognition rates?

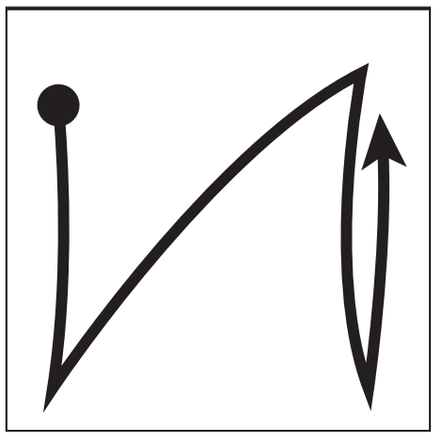
question::

does the length of patterns lead to different recognition rates?

I

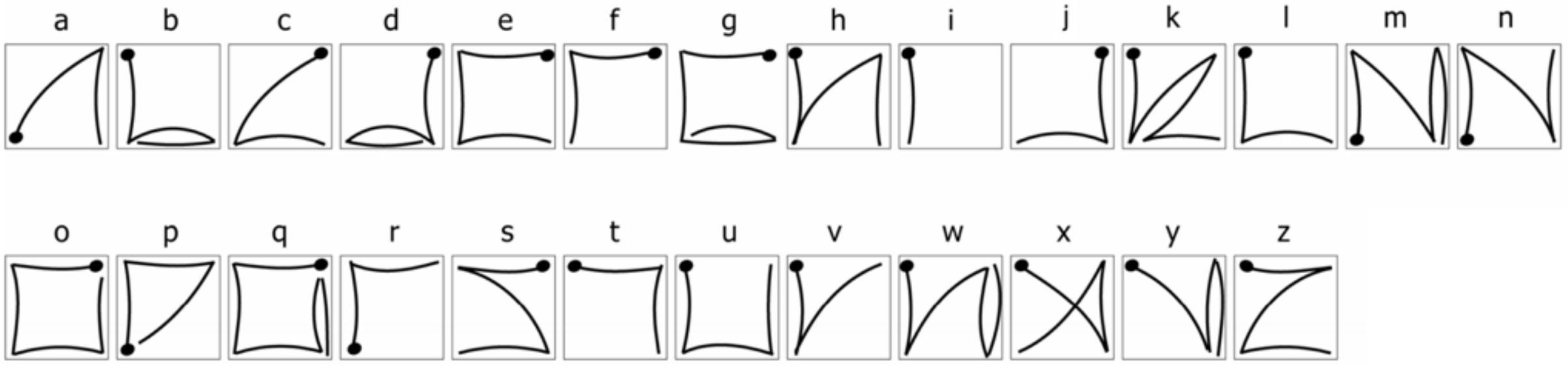


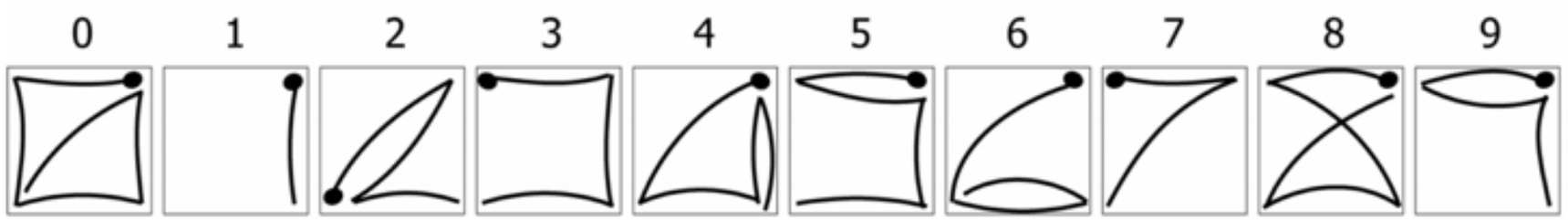
W

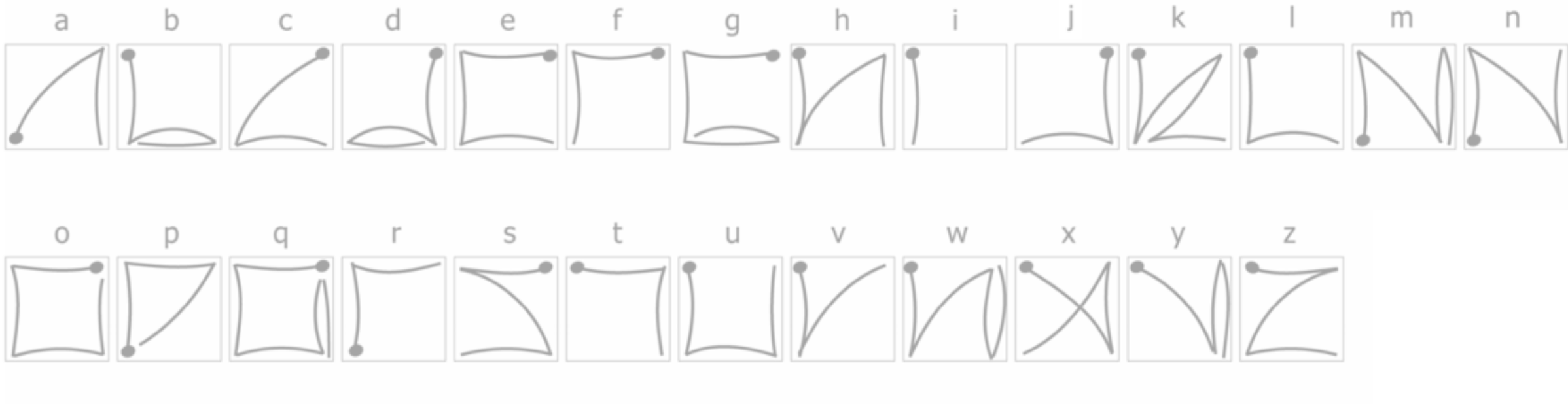


2

recognizable length of EdgeWrite

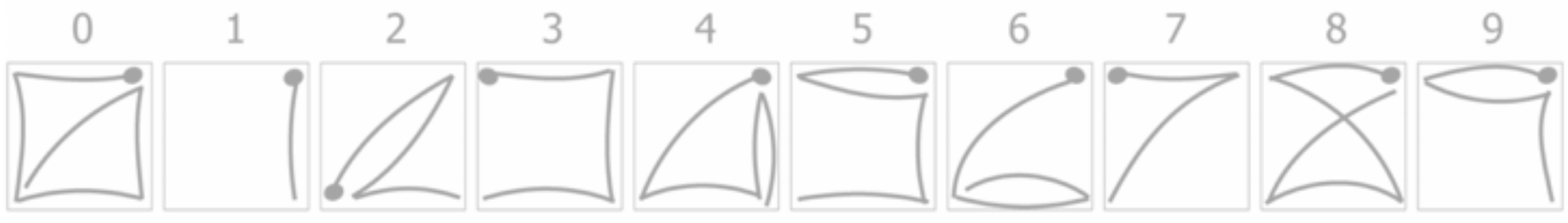

a b c d e f g h i j k l m n
o p q r s t u v w x y z


0 1 2 3 4 5 6 7 8 9



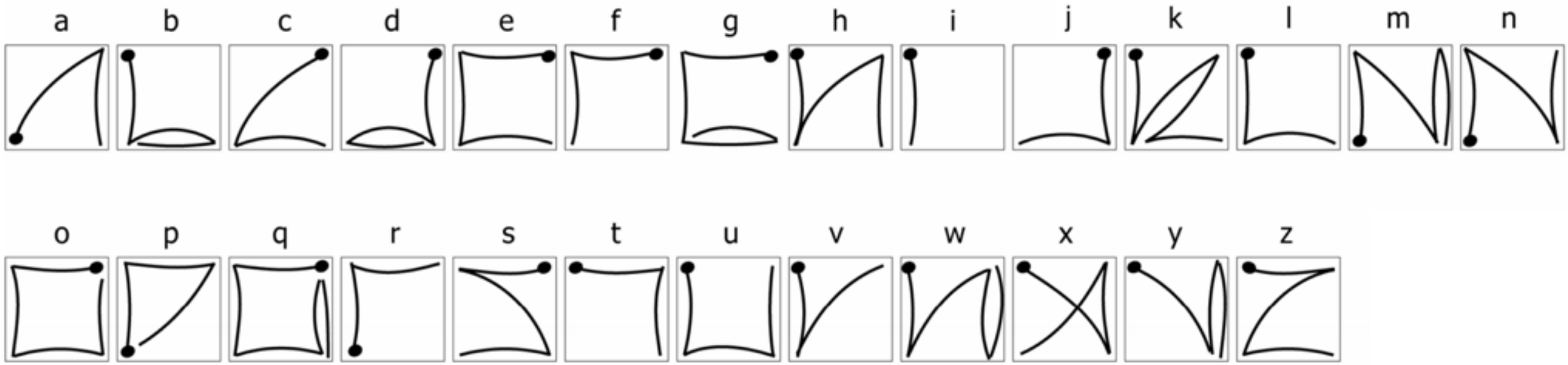
12 participants

26 patterns x 4 rounds

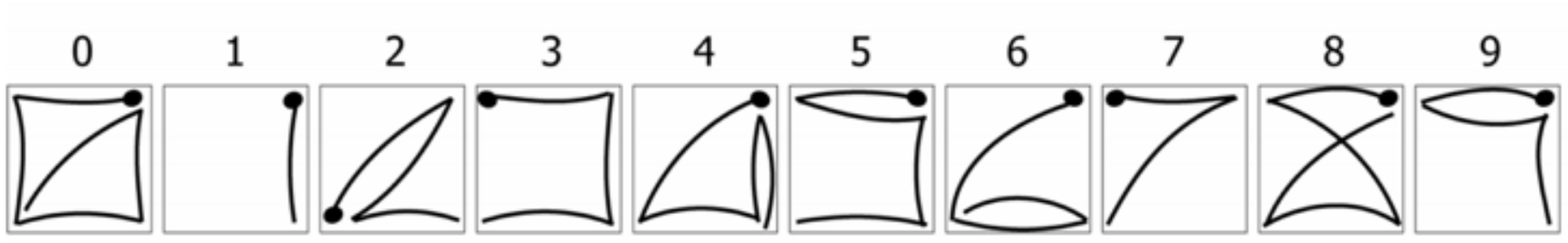


12 participants

10 patterns x 4 rounds



accuracy: 70.7%



accuracy: 78.5%

Vibration Counts	Letters	
2	i	100%
3	a c f j l r t v	76.1%
4	b d e h n p s u x y z	63.8%
5	g k m o w	66.4%
6	q	91.4%

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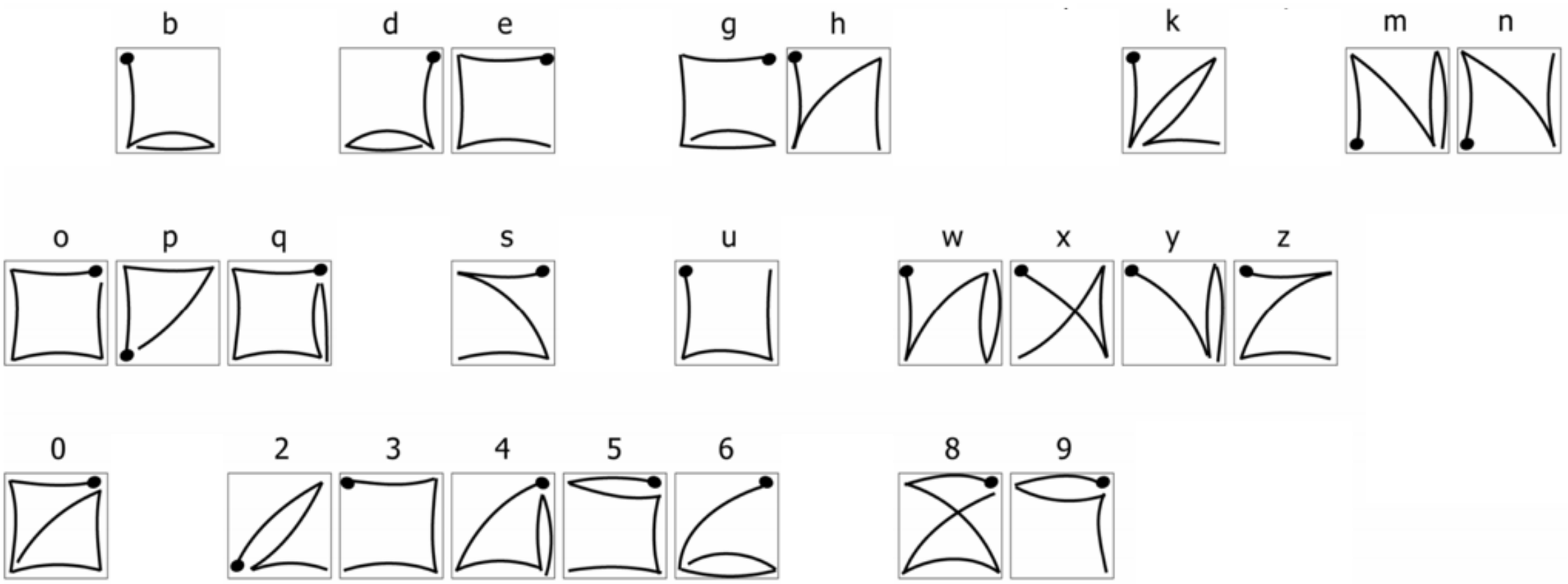
recognizable length of EdgeWrite:: 3



divide patterns into multistroke ones

question::

more than one possible segmentations, which one is more effective?

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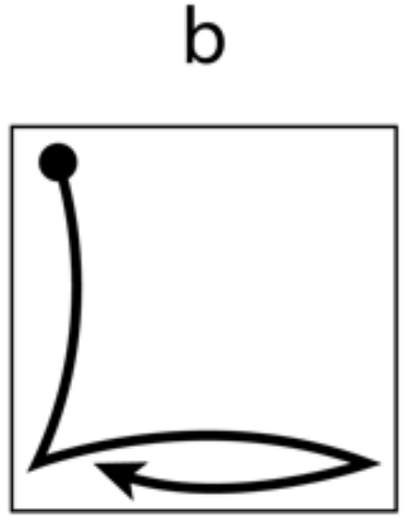

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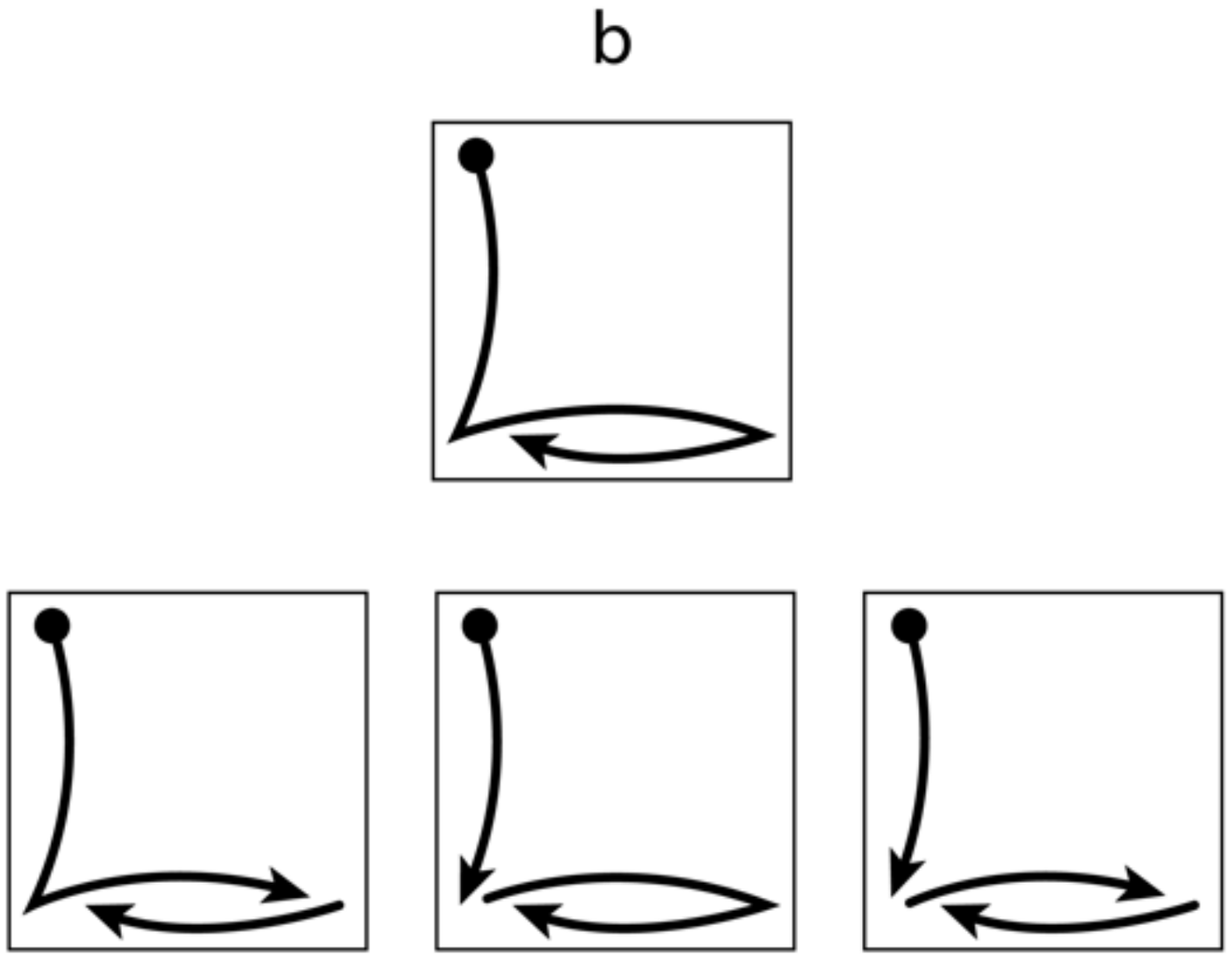
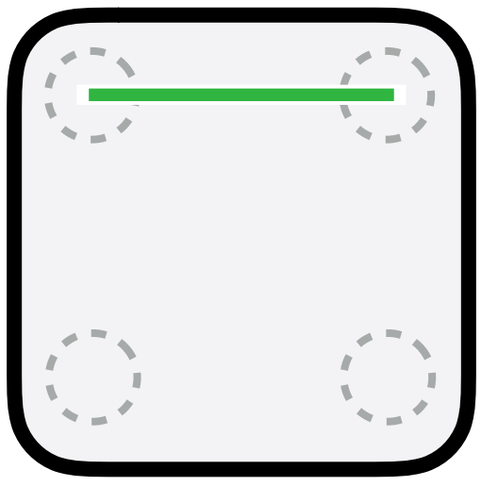
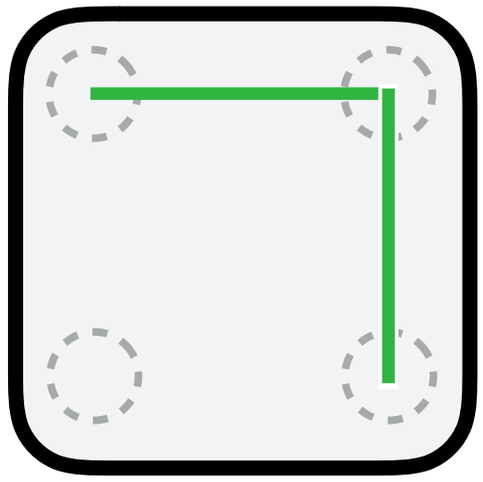


#3

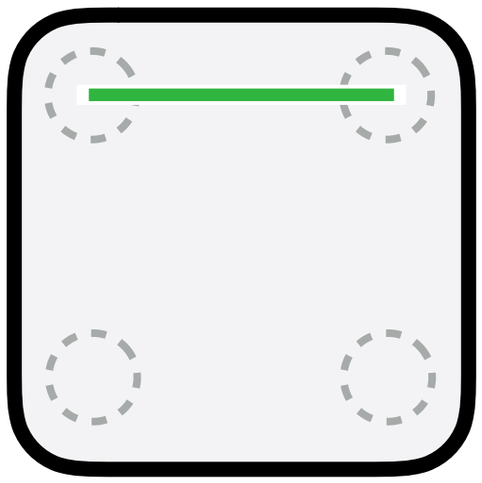
optimal segmentation of EdgeWrite



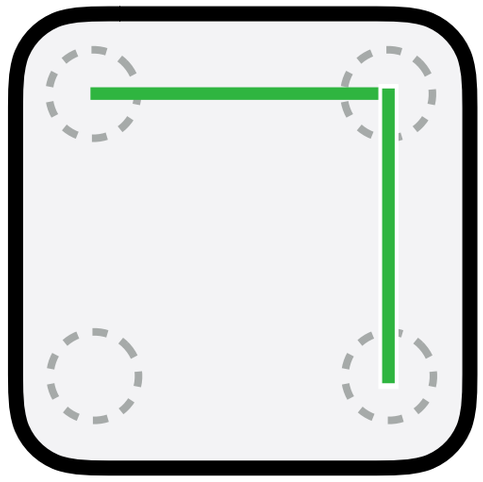
2-vibration pattern



3-vibration pattern

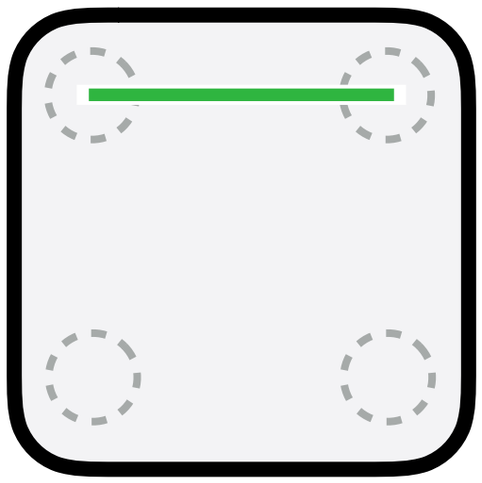


2-vibration pattern



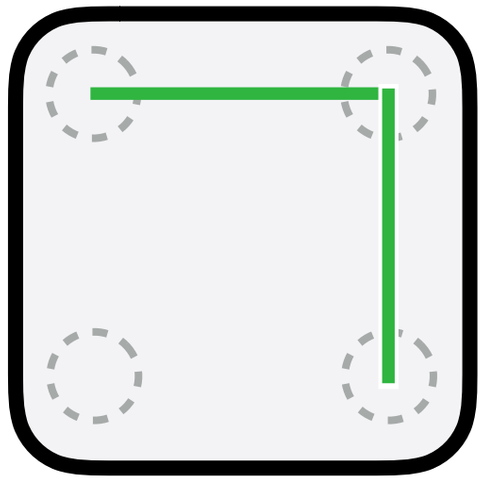
3-vibration pattern

12 participants
36 patterns x 4 rounds



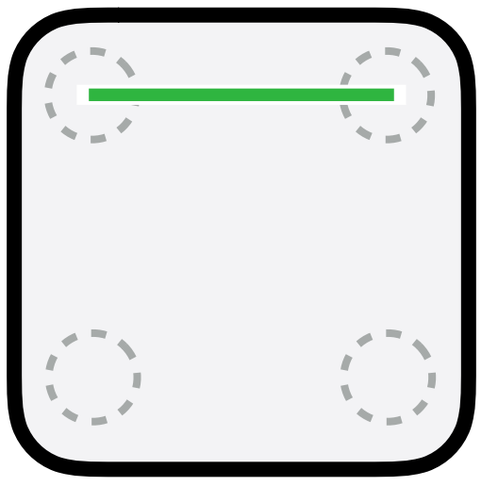
2-vibration pattern

accuracy: 79.3%

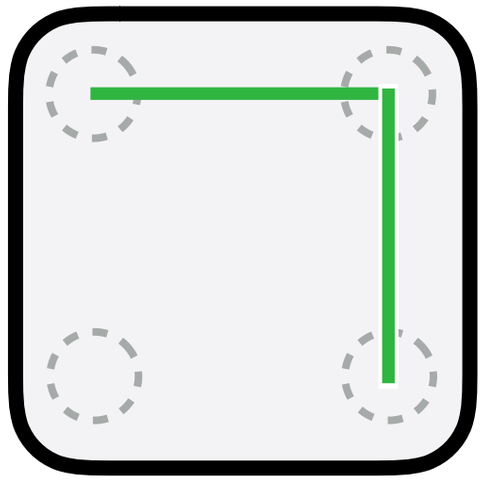


3-vibration pattern

accuracy: 79.0%

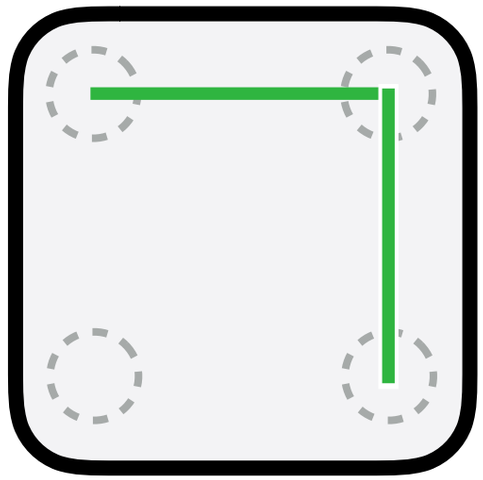


2-vibration pattern



3-vibration pattern

2-vibration pattern



3-vibration pattern

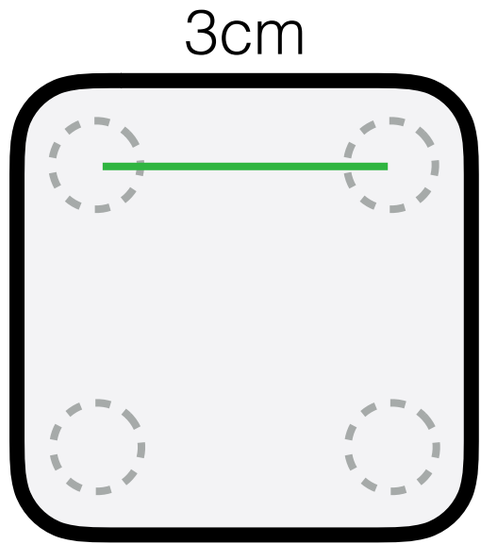
efficient in stroke numbers

findings

how to effectively display alphanumeric patterns on the wrist?

study 1::

optimal resolution:: **2x2**



study 2::

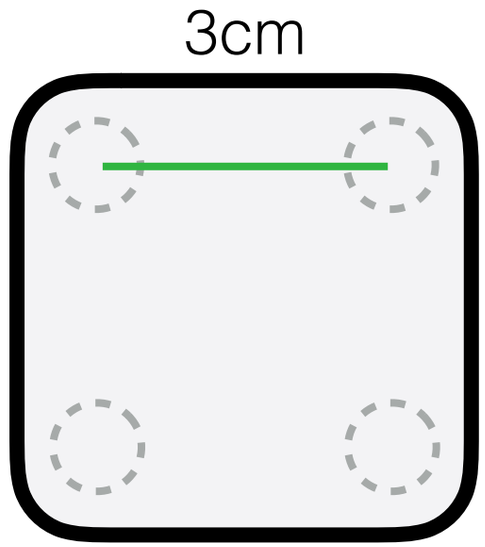
recognizable length of EdgeWrite:: **3**

study 3::

optimal segmentation:: **3-vibration first**

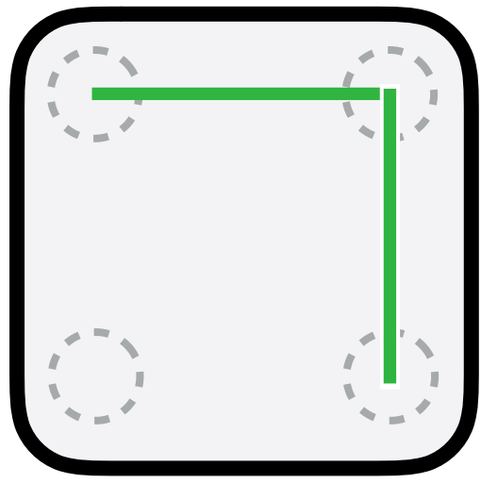
study 1::

optimal resolution:: **2x2**



study 2::

recognizable length of EdgeWrite:: **3**

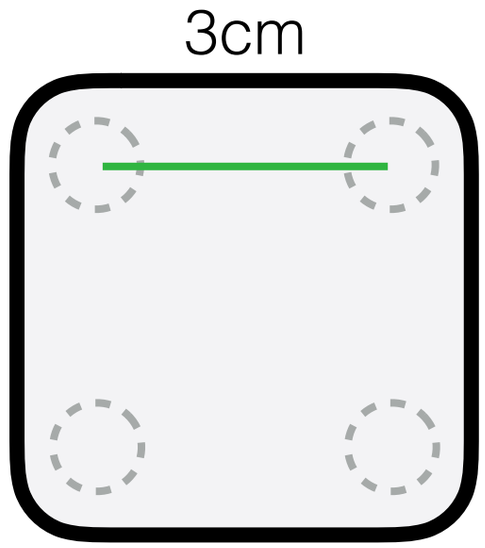


study 3::

optimal segmentation:: **3-vibration first**

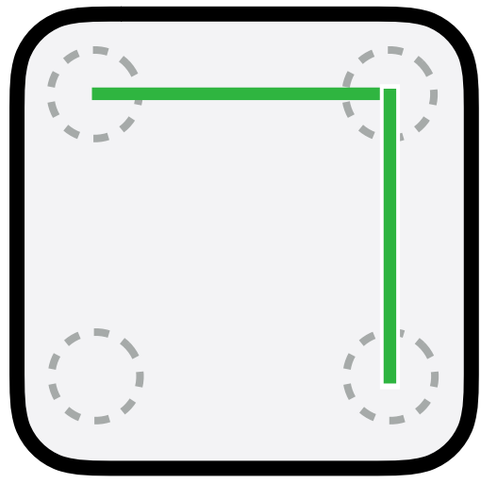
study 1::

optimal resolution:: **2x2**



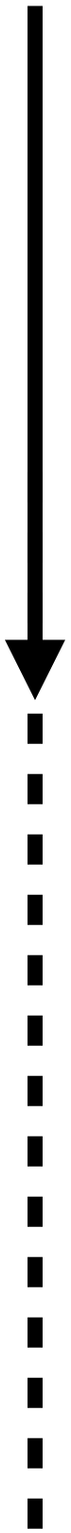
study 2::

recognizable length of EdgeWrite:: **3**



study 3::

optimal segmentation:: **3-vibration first**



Introduction

User Studies

Design Principles

Evaluation

Discussion

Conclusion

Design Principles

1. apply as many 3-vibration strokes as possible

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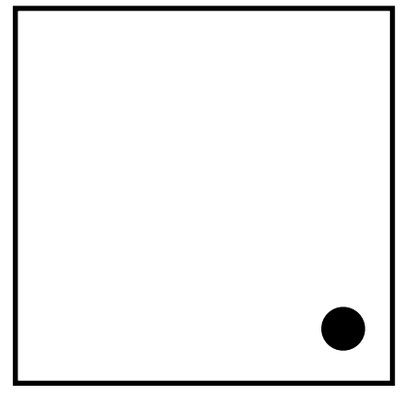
2. if a pattern cannot be totally subdivided into 3-vibration strokes, include 2-vibration strokes

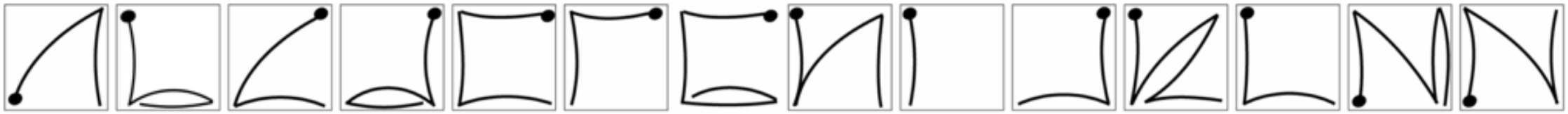
1. apply as many 3-vibration strokes as possible

2. if a pattern cannot be totally subdivided into 3-vibration strokes, include 2-vibration strokes

3. delimiter is required in multistroke design to clearly indicate the end of a pattern

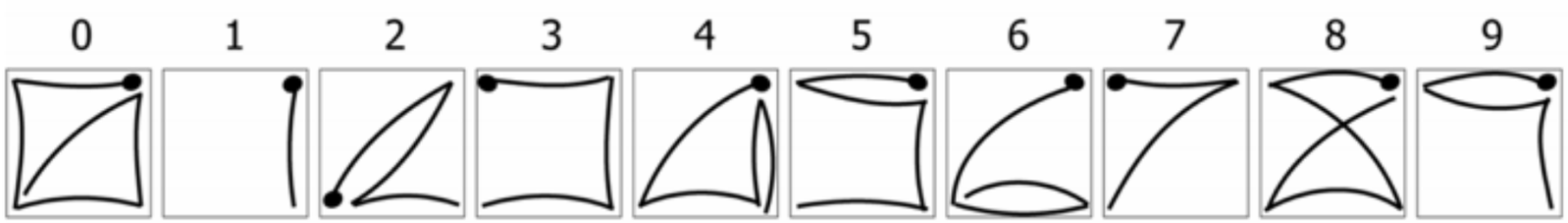


a b c d e f g h i j k l m n

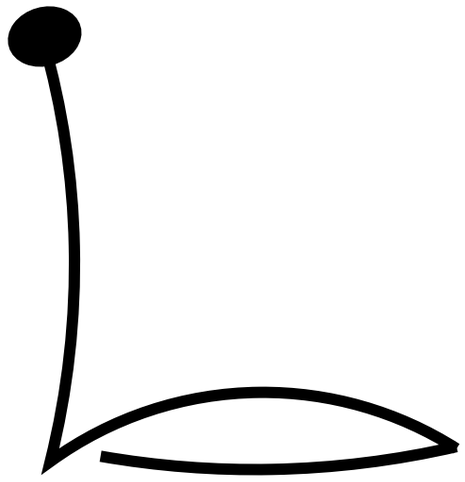


o p q r s t u v w x y z

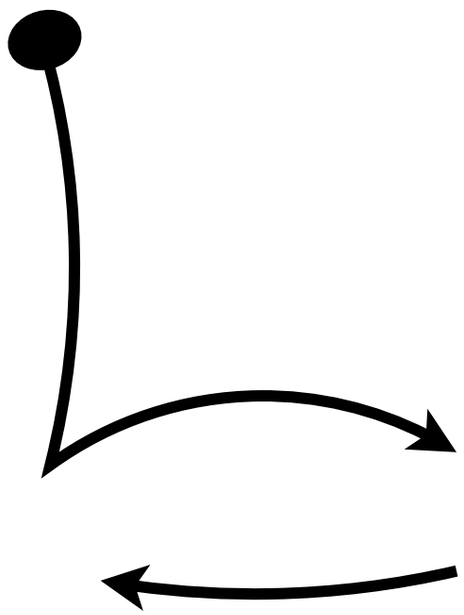
0 1 2 3 4 5 6 7 8 9



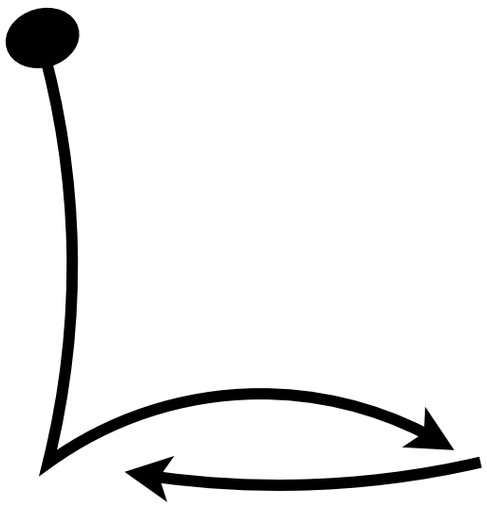
take letter “b” as example



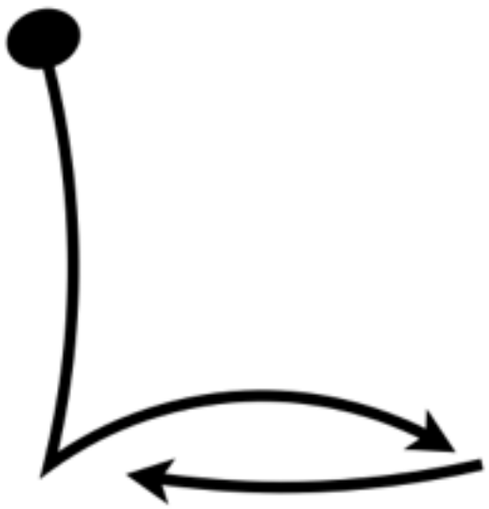
take letter “b” as example



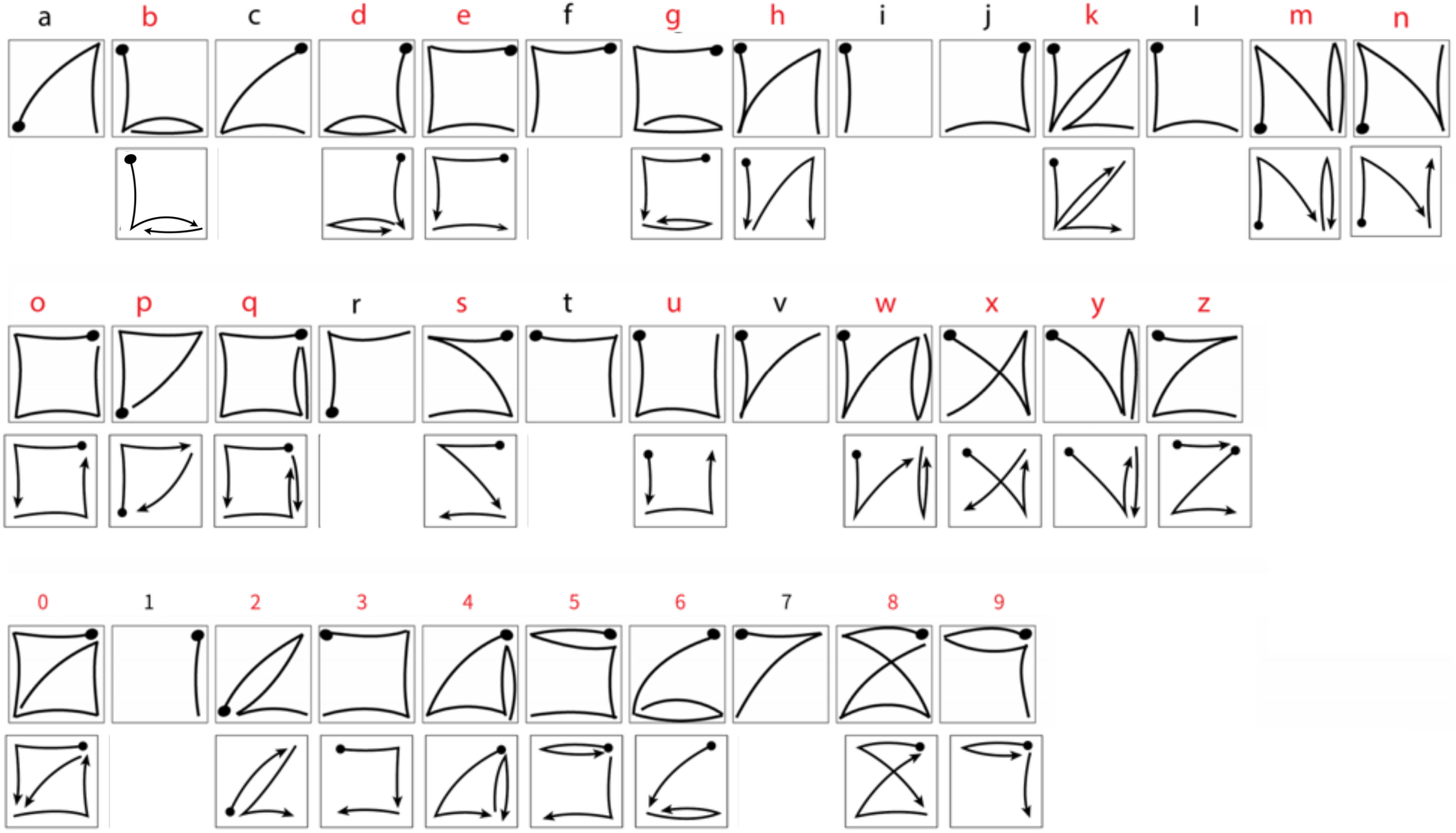
take letter “b” as example



take letter “b” as example



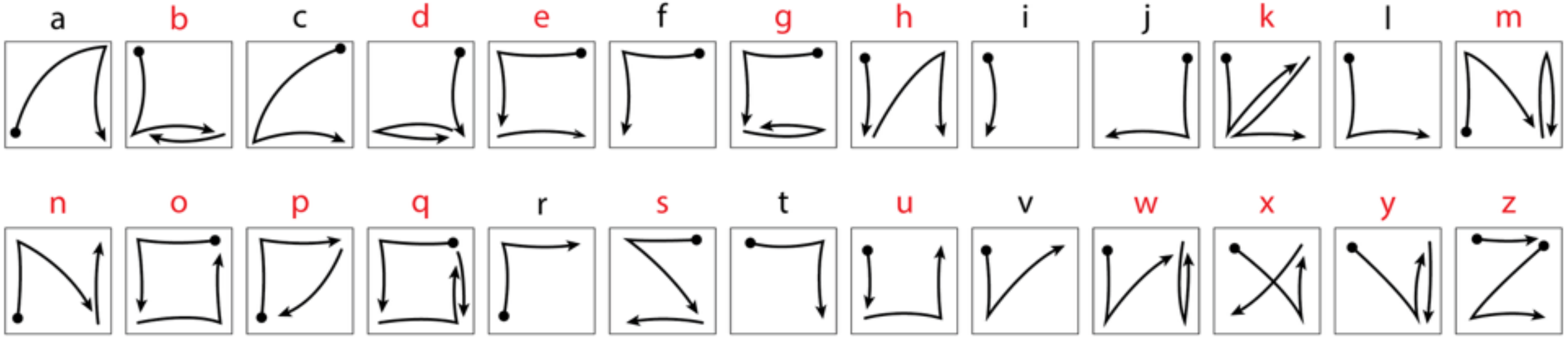
take letter “b” as example



the derived EdgeVib patterns

Evaluation

1. single characters
2. two-character messages


a
b
c
d
e
f
g
h
i
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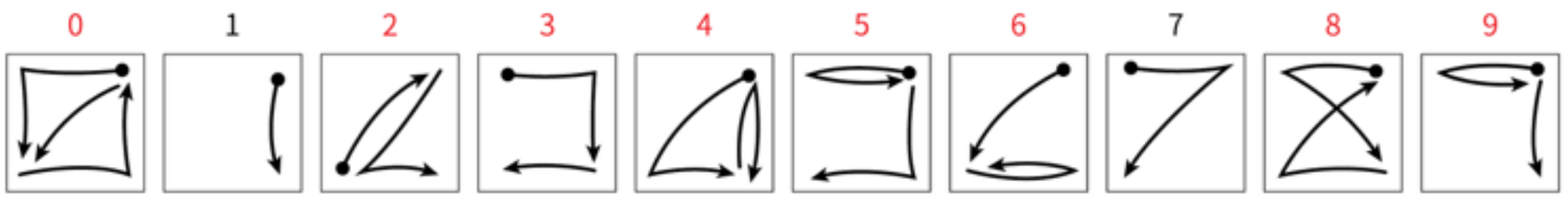
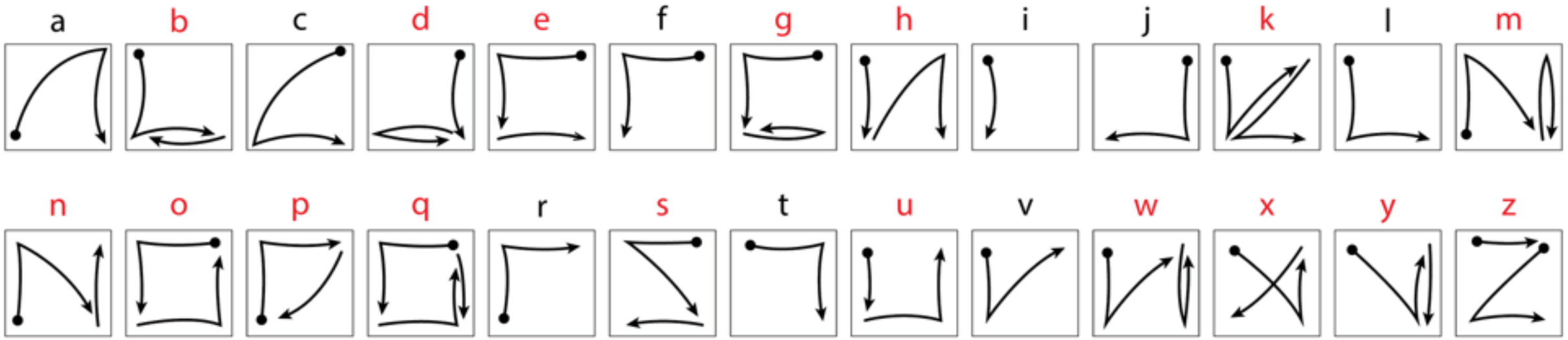
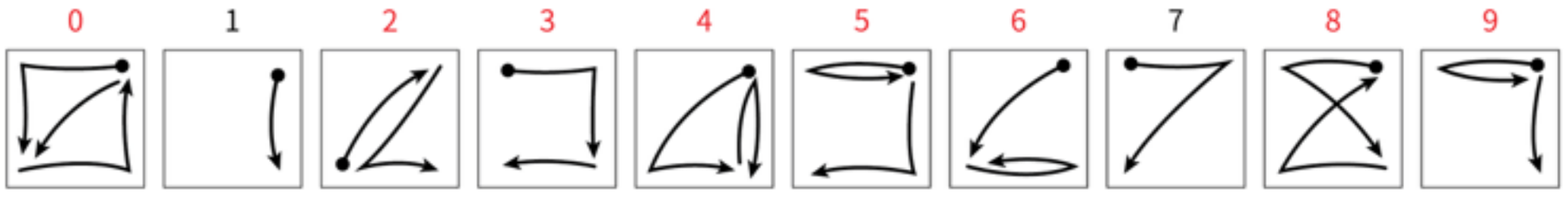
k
l
m
n
o
p
q
r
s
t
u
v
w
x
y
z


0
1
2
3
4
5
6
7
8
9

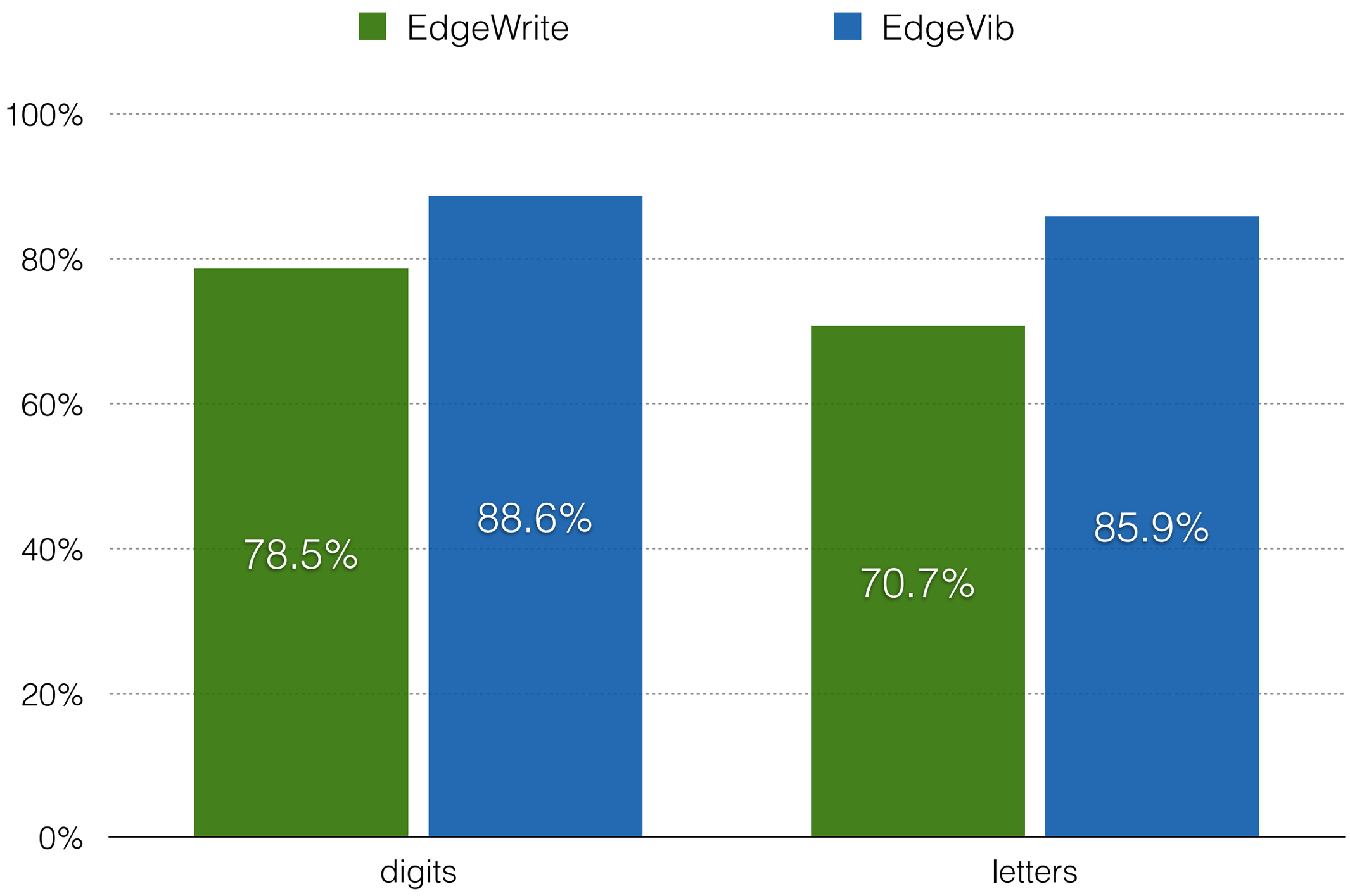
before actual testing,
participants learned the writing of
original **EdgeWrite** patterns



accuracy: 85.9%

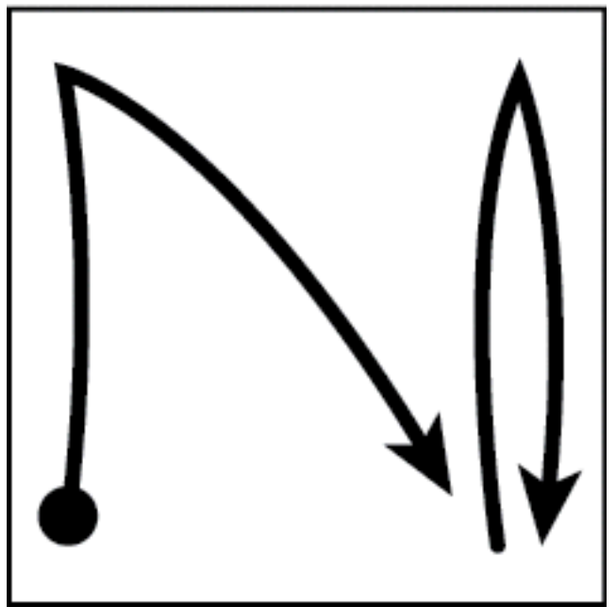


accuracy: 88.6%

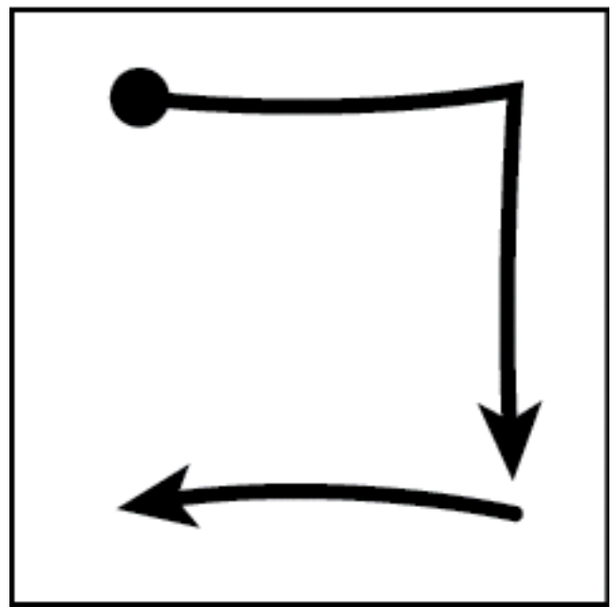


both showed significant difference ($p<0.05$)

M

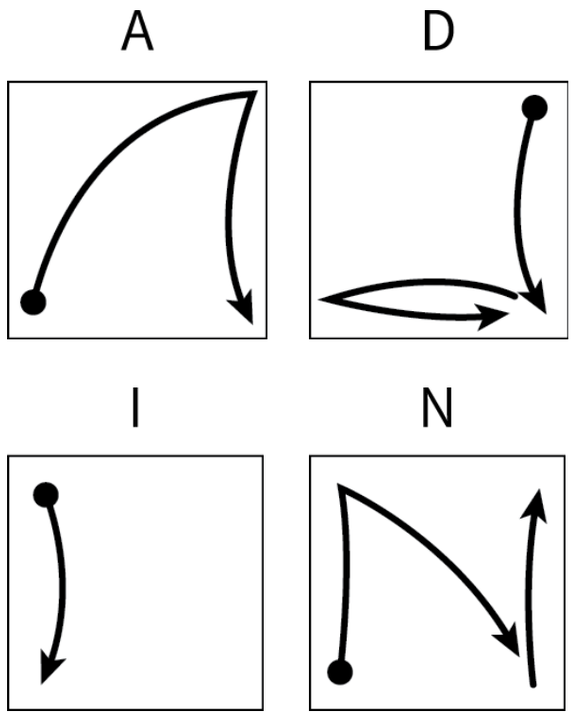


3

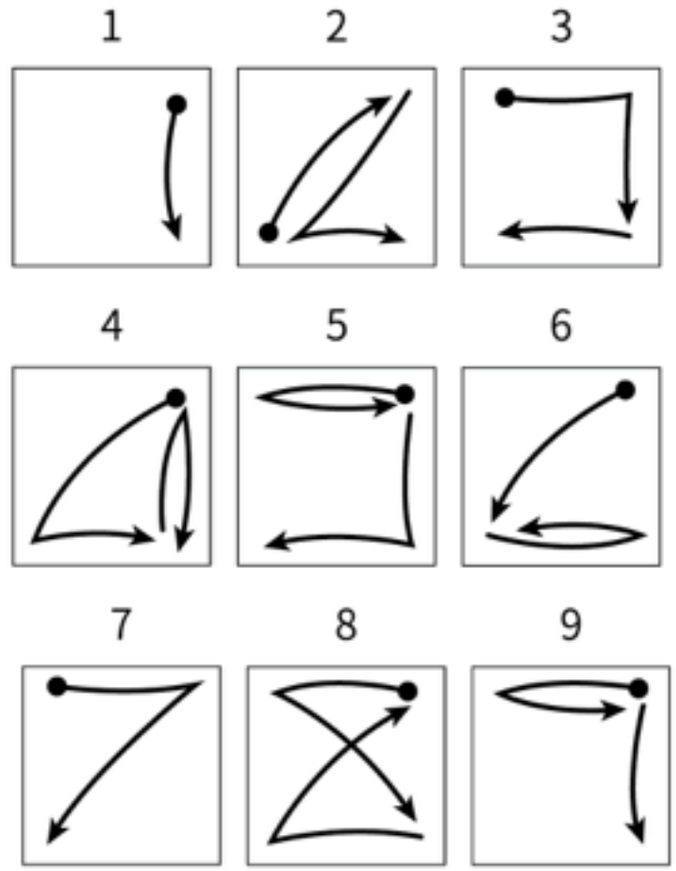


results of accuracy

easiest

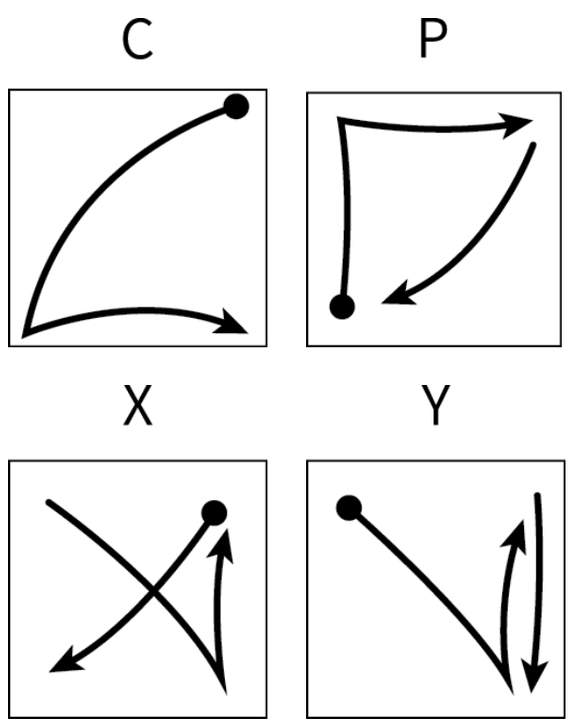


\+



89%

hardest



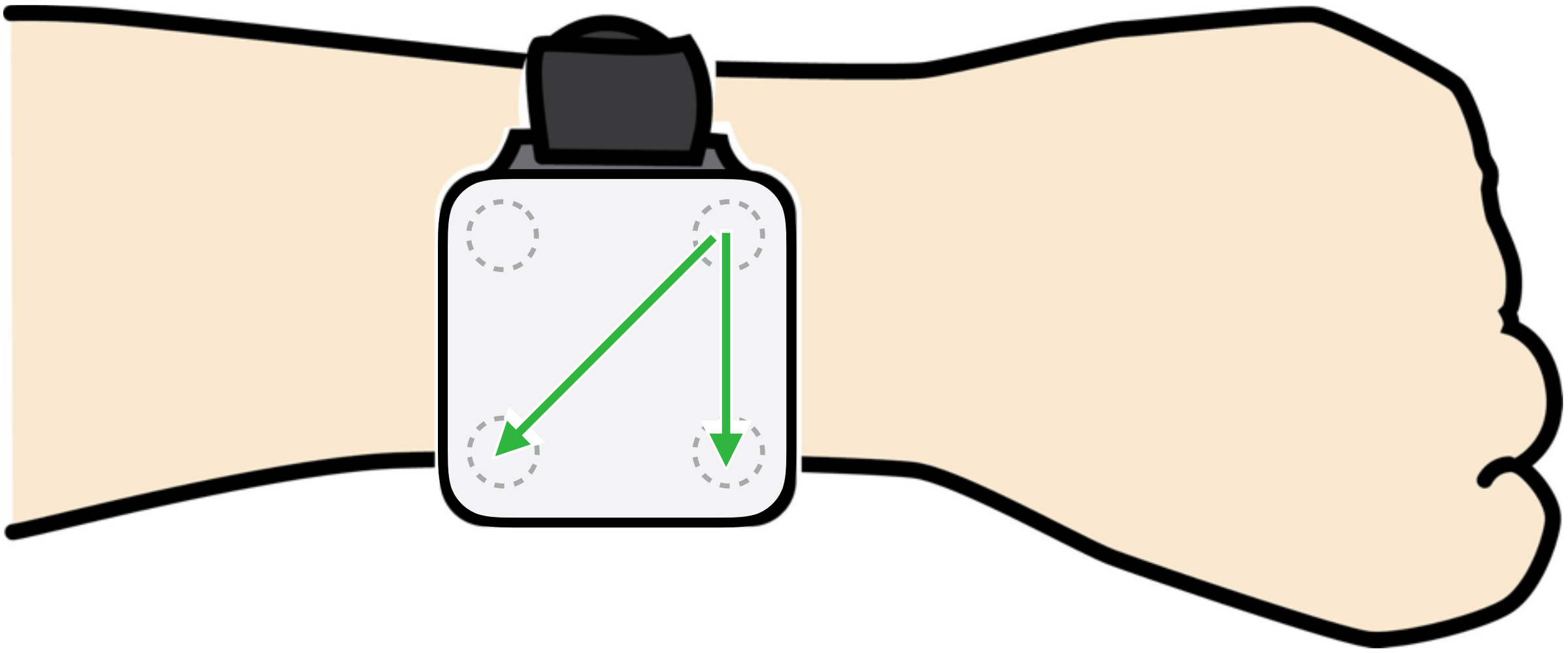
\+

83.3%

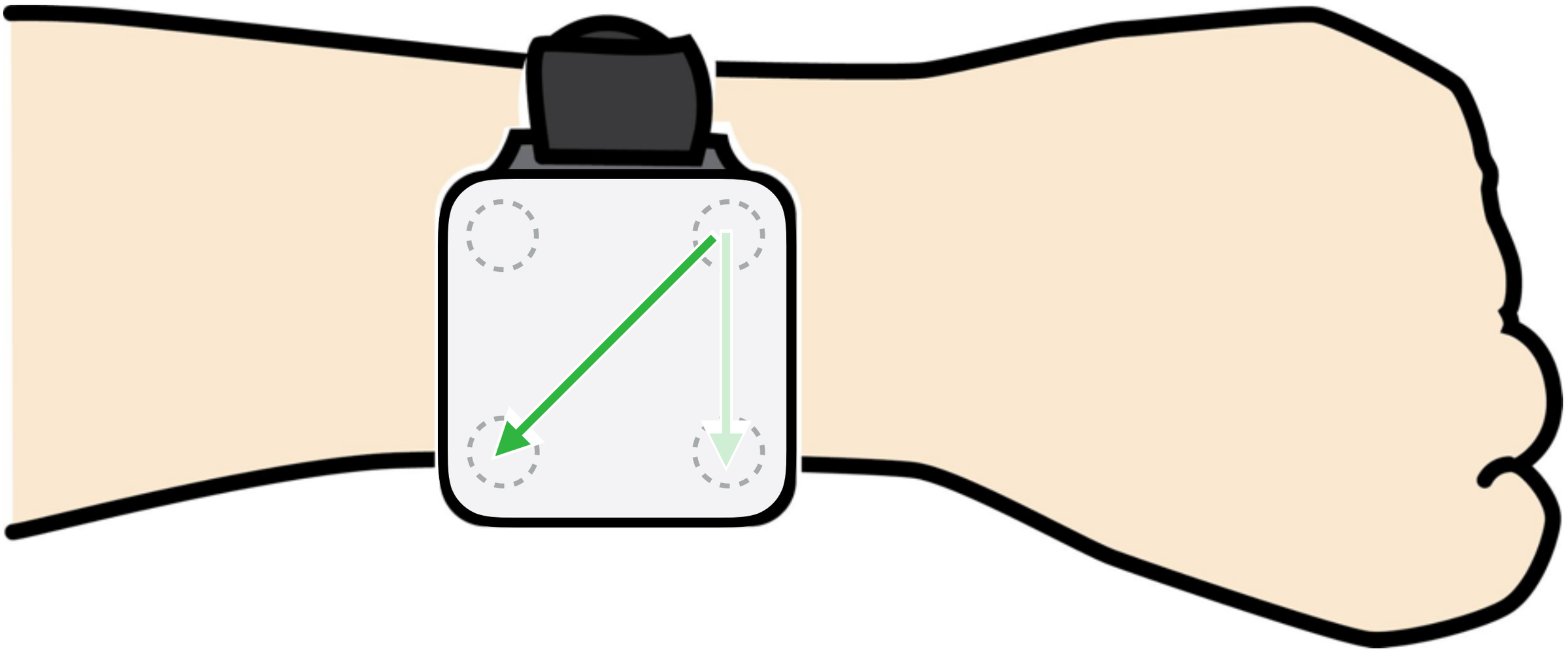
Discussion

1. limitation
2. possible applications
3. future work

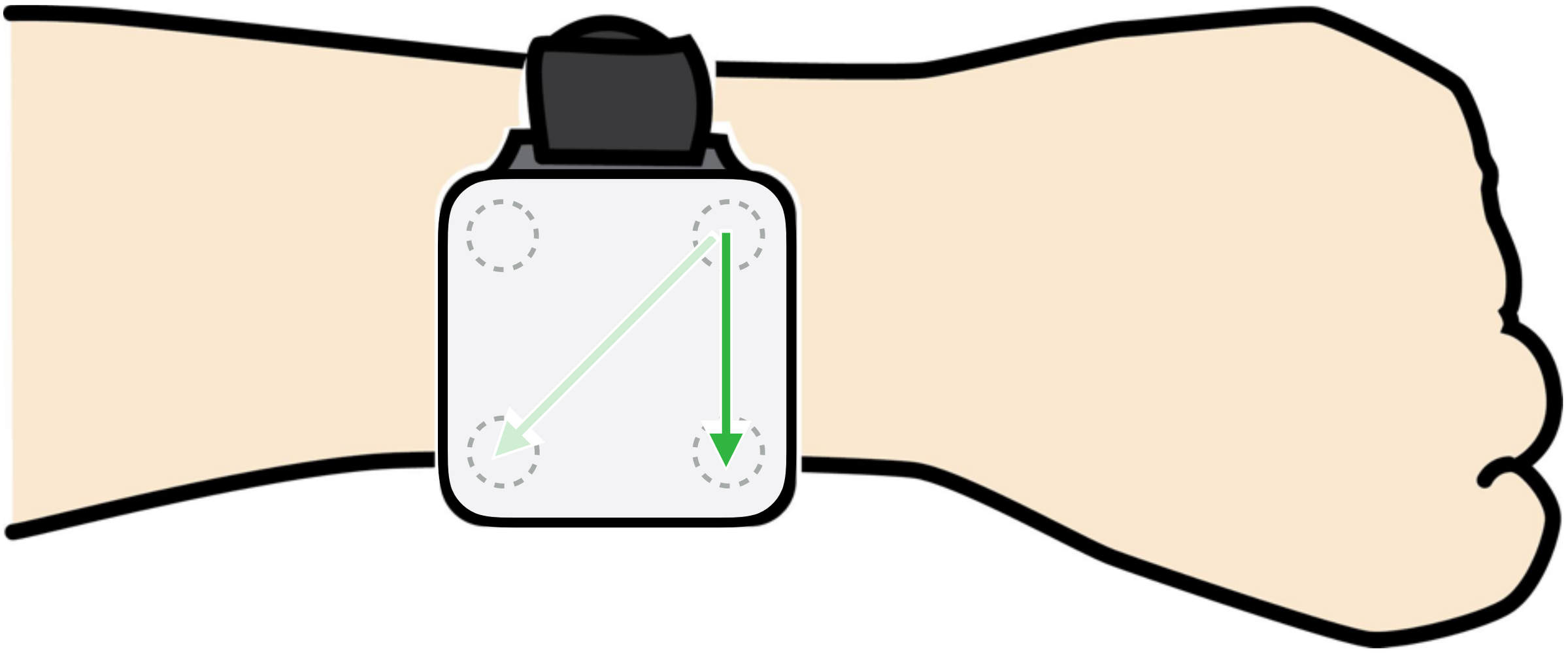
users’ confusion between vertical and diagonal strokes



confusion between vertical and diagonal lines

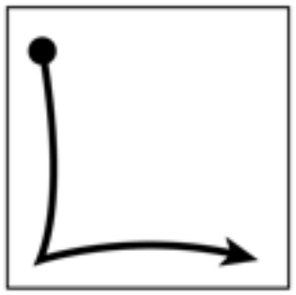


confusion between vertical and diagonal lines

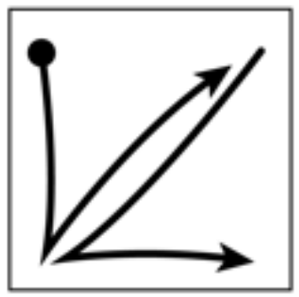


c

l

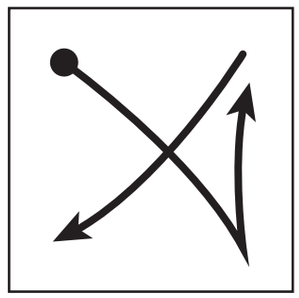


k



w

x



y

c

l

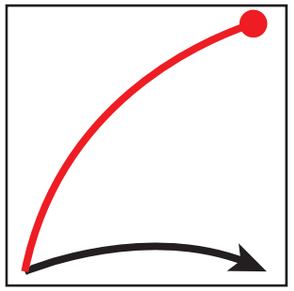
k

w

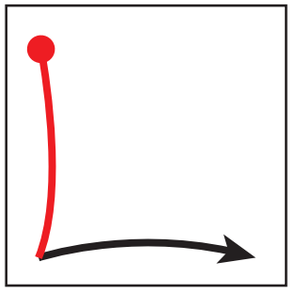
x

y

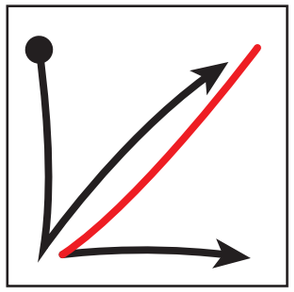
c



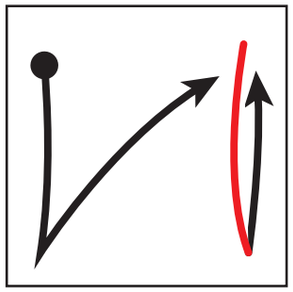
l



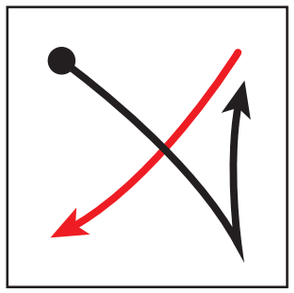
k



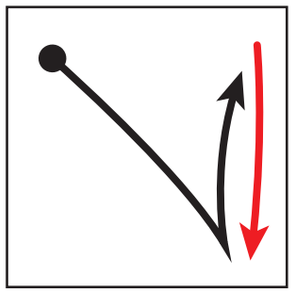
w



x



y



c

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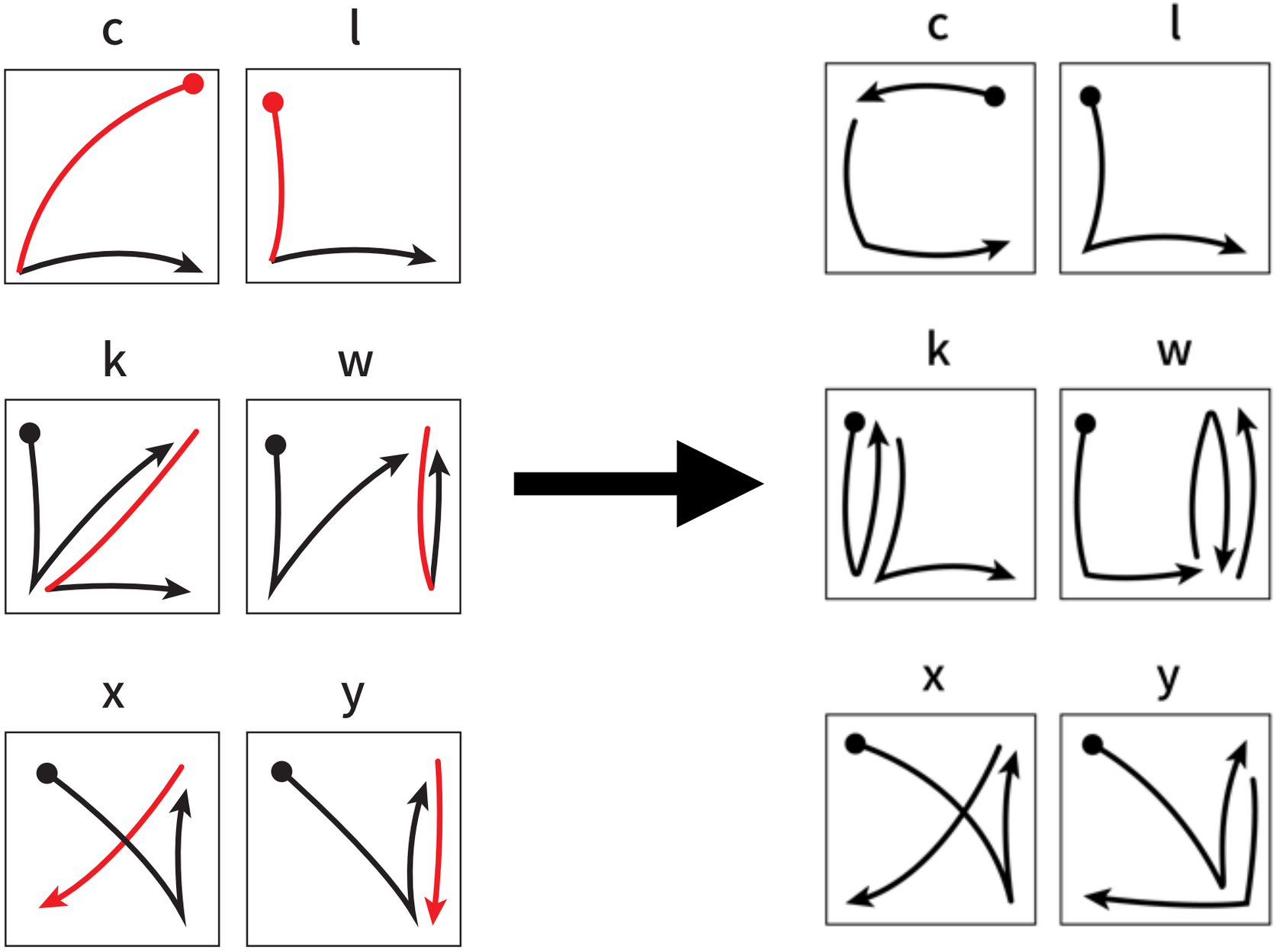
x

y


c
l
k
w
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Discussion

1. limitation
2. **possible applications**
3. future work

1. **rich** and **private** communication

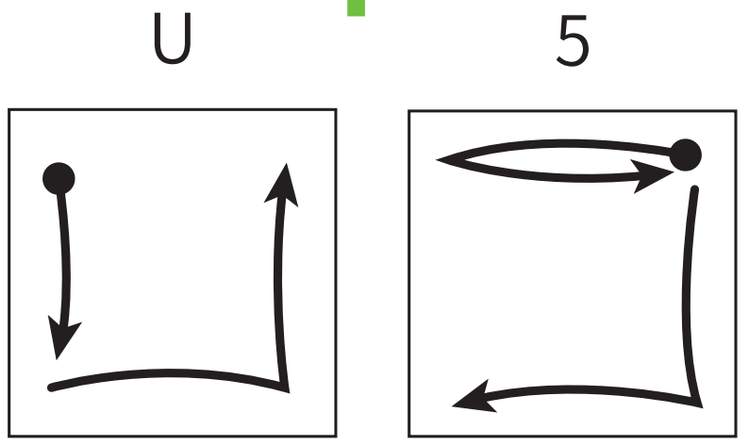
2. **informative** notification

UBER

UBER

U

5



Uber coming in 5 mins

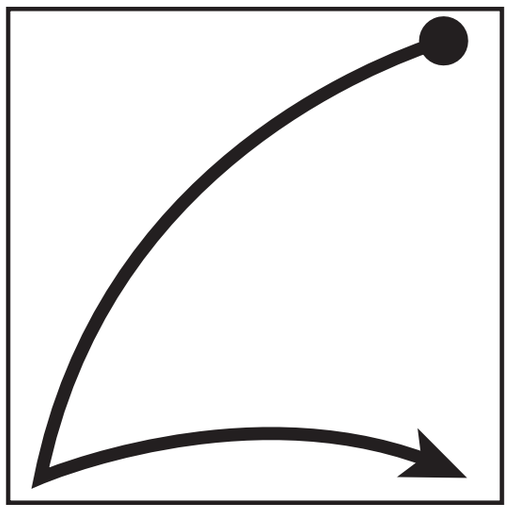
1. **rich** and **private** communication

2. **informative** notification


Pokémon
GO
AR
Pikachu
CP 62

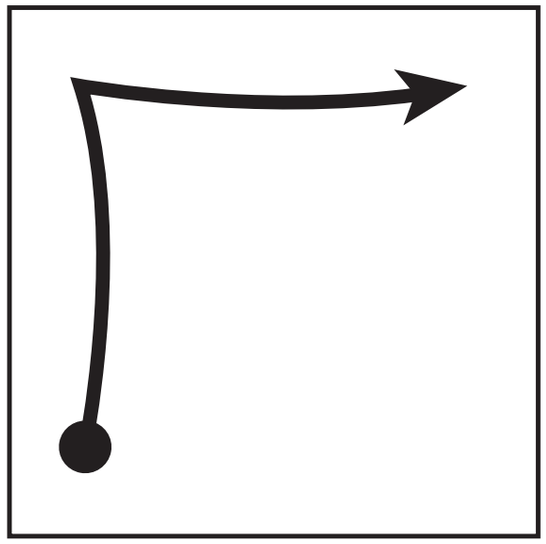
+ EdgeVib

C



common pokemon

R



rare pokemon

Discussion

1. limitation
2. possible applications
3. **future work**

future work

enhancing time efficiency

eliminating respond time of vibrators

performance in a real-world environment

multi-tasking

different hand postures

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Introduction

User Studies

Design Principles

Evaluation

Discussion

Conclusion

Conclusion

how to effectively display alphanumeric patterns on the wrist?

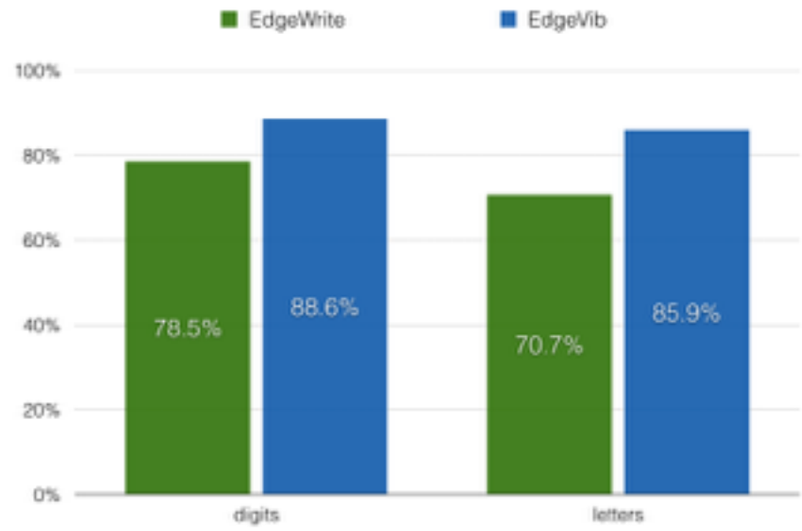
multistroke patterns

Letter “b”

multistroke patterns

Letter “b”

performance

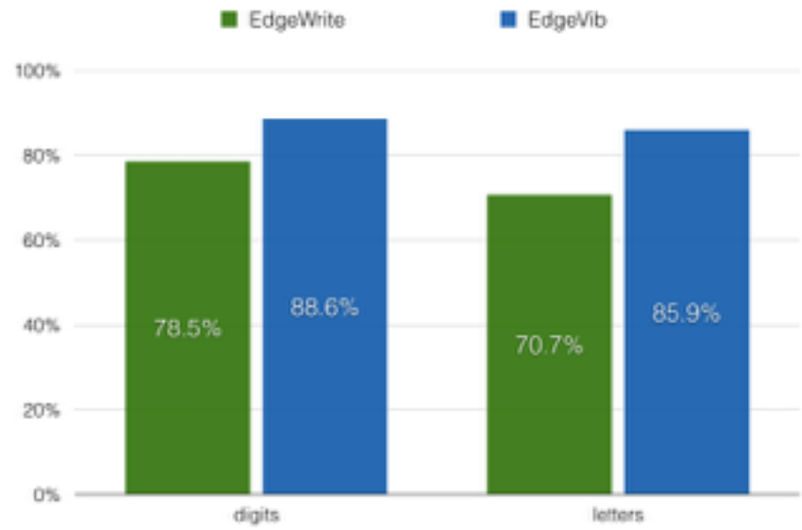


both showed significant difference under t-test ($p<0.05$)

multistroke patterns

Letter “b”

performance



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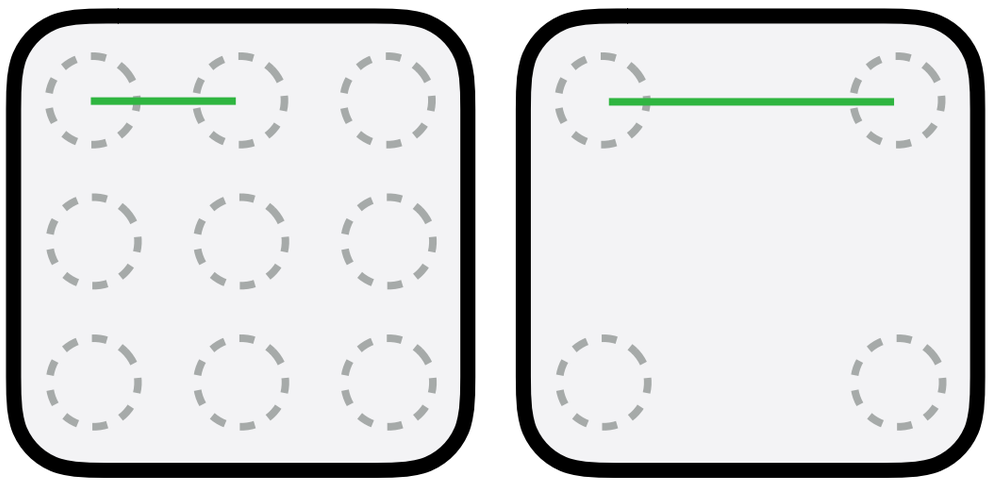
studies



multistroke patterns

Letter “b”

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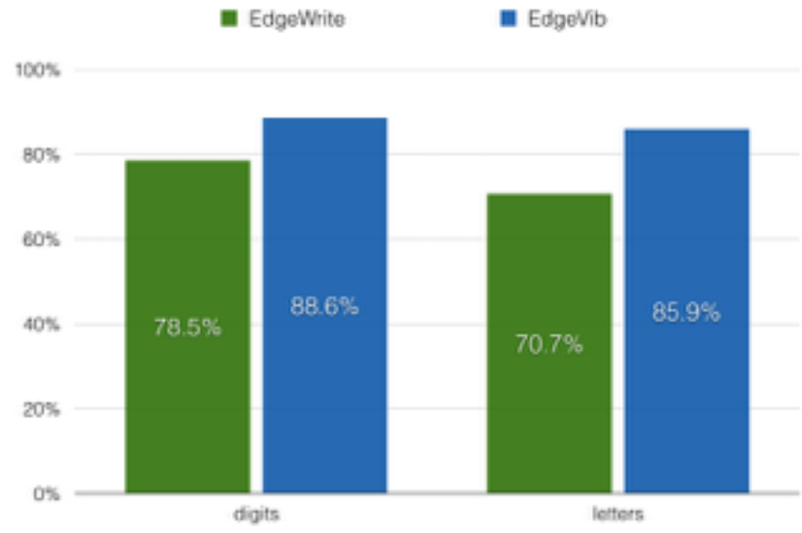

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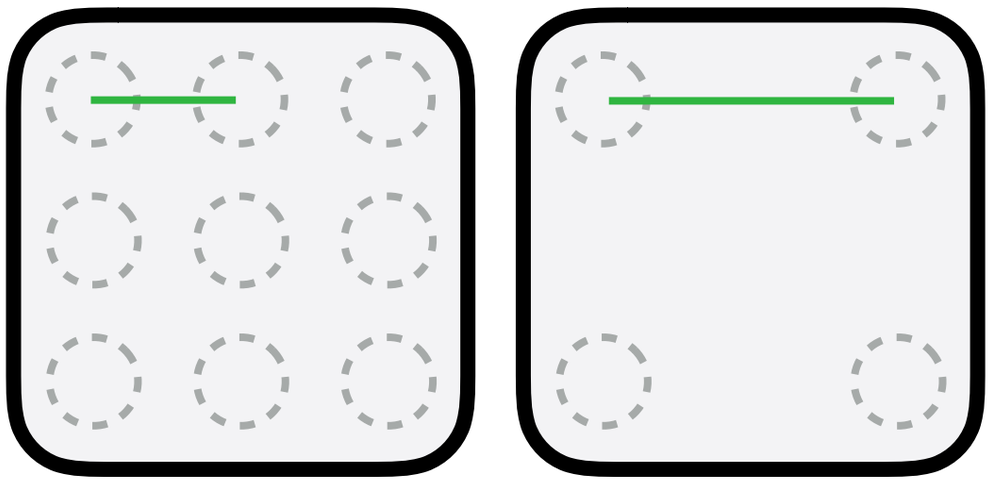


design guidelines

1. apply as many 3-vibration strokes as possible

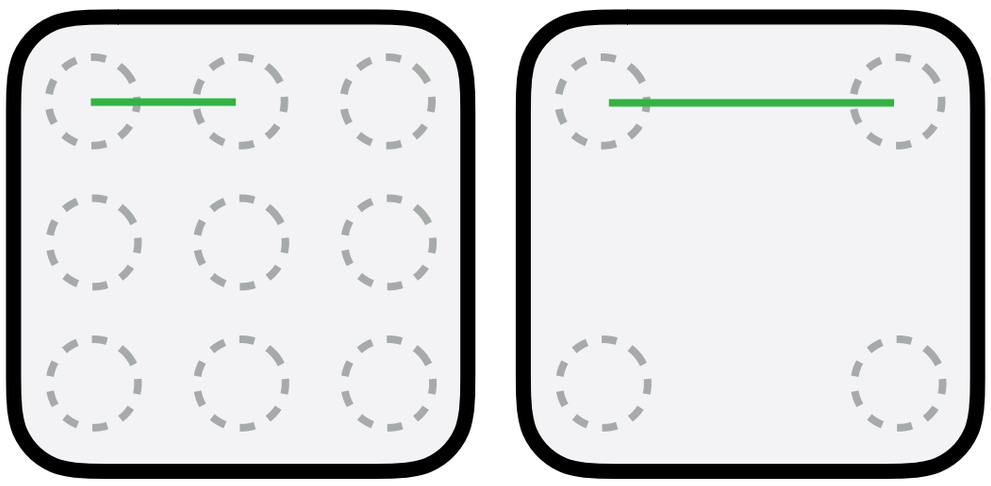
2. if a pattern cannot be totally subdivided into 3-vibration strokes, include 2-vibration strokes based on the expected combinatorial accuracy

3. delimiter is required in multistroke design:
   Right-down corner with 200 ms vibration.

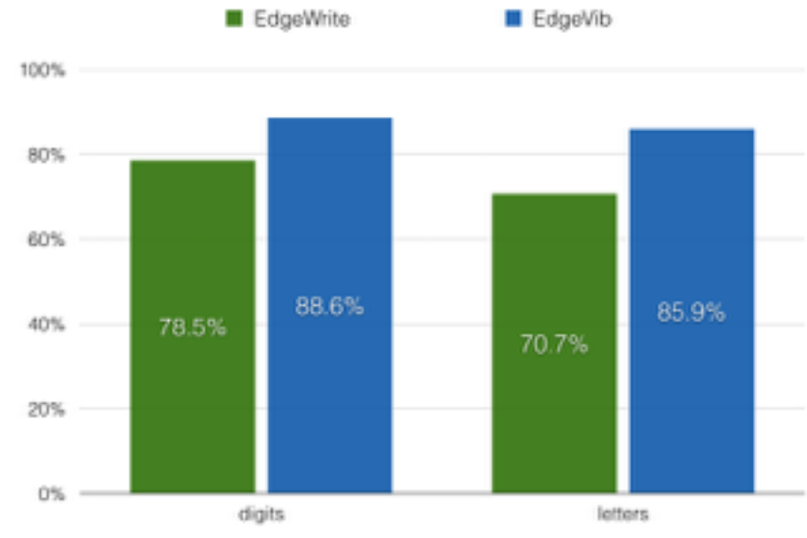
multistroke patterns

Letter “b”

studies



performance



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effective alphanumeric character output using a wrist-worn tactile display

Yi-Chi Liao, Yi-Ling Chen, Jo-Yu Lo, Rong-Hao Liang, Liwei Chan, Bing-Yu Chen