# Vernier perceptual learning transfers to completely untrained retinal locations after double training: A "piggybacking" effect

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**Perceptual learning, a process in which training improves visual discrimination, is often specific to the trained retinal location, and this location specificity is frequently regarded as an indication of neural plasticity in the retinotopic visual cortex. However, our previous studies have shown that "double training" enables location-specific perceptual learning, such as Vernier learning, to completely transfer to a new location where an irrelevant task is practiced. Here we show that Vernier learning can be actuated by less location-specific orientation or motion-direction learning to transfer to completely untrained retinal locations. This "piggybacking" effect occurs even if both tasks are trained at the same retinal location. However, piggybacking does not occur when the Vernier task is paired with a more location-specific contrast-discrimination task. This previously unknown complexity challenges the current understanding of perceptual learning and its specificity/transfer. Orientation and motion-direction learning, but not contrast and Vernier learning, appears to activate a global process that allows learning transfer to untrained locations. Moreover, when paired with orientation or motion-direction learning, Vernier learning may be "piggybacked" by the activated global process to transfer to other untrained retinal locations. How this task-specific global activation process is achieved is as yet unknown.**

## Introduction

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B , , ,
L
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(K &
1991; F , , 1994; , , , & O , 1995;
C , K , , & G , , 1997; B ,, ,
B , L , & P , 2011). A, , ,

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, (M ,, & D , , 1996; D & L , 1999; , K, , & L , 2004; P ,., 2005). , - , , (A & H , 1997; J , D , P , & L , 2009).

, , , , , , , , . I , , , , , , , 1 (A & H , 1997). H , ,, , , , , ( ,., 2008; K, , L , & , 2012; , C , & , 2013), ,, , ,, , - , - ,, ( PE) , , , , . ., (J. . ,., 2010; J. . , C , K, , L , & , 2014; J. . & , 2014). , , , , - , , , ,, , , , , , . , , ,, , , , ,, . , , , , , , , , , , , - -, , - , , (J. . ,., 2010). , , , , , , , - , , , , , , . O , , , , , , -, , , ,, - , , ( ,., 2008). M , , , , L , (2013) - ,, ( . ., , ), , , - - , -, , , - , , , . - , , , , . I , D L , -, ,, , -

, , , , (D , J , L , & L , 2013). L , - - , -, , , - , , , , , , - , , , (L , L , & D , 2011).

, , , . H , , , , , , , , . , , , , , , , . ,, ,, , , . , ,, , , , , , , , .

# Methods

## Observers and apparatus

D ,, 76 ( , 20 ). A,, , - - , , , ï . I ,, . , M , - (N I , O , , CA) 21- . G520 , ( , : 2048 , × 1536 ,, 0.19 (H) × 0.19 ( ) ,, 75 H ; , : 1024 , × 768 ,, 0.38 (H) × 0.38 ( ) ,, 120 H ). , 50 / $^2$. 8- , , , - , . , , - - , , . E , , .

## Stimuli

, , G (G - , ) , , - , (F 1 ).

a

c

G , (3 ), , 25 ,
(0.29°), (0.47), (4 × 4 , ) , (
( , ,), - - , ) 2°- ,
4$\lambda$. , , (F 1 ). E
G , , 250 . ,
, G , , ,
. , ,
- , ,, , , . A,,
, , ±15 . (36° 126°)
G 0.47 7°/ . O ,
0.47 + ΔC. ,, , , .
5° 10° 1.5 ,
0.75 , , . G ( , = 1.5 ,

G . A ,, ,
, 500
,. A ,, , -
, , G
, 2- , - (F 2 -
). A .
D ,
, 2- , - (2-IFC)
. I ,,
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( + Δ ) ,
100- , ,
500- , ,.
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, , , 3- -
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50 60 , ). 0.05 ,
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## Statistical analyses

(PI).
PI = 100% × ( − )/ . H
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A ( I) I = MPI /
MPI ,
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I = 1 I = 0. *p* , , , $p_1$ I

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(         ,., 2012).     ,
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(                 ," F      1 ).
,          ,    ,  ,          ,
( I) = −0.10 ± 0.16 (   ,   ,
F      3;  ,          ,., 2008;          ,.,
2012),          ,          I = 0 ($p_0$ = 0.26;
$p_0$    $p_1$    $p$   ,        I          I
= 0     I = 1,        ,  ).       ,     (MPI =
37.2 ± 2.9%, $p$ < 0.001,          ,, 25
F     1),          ,       (MPI =
31.6 ± 6.4%, $p$ < 0.001; F     1 ),          ,
(MPI = 41.0 ± 8.4%, $p$ = 0.014; F     1 ),
,       (MPI = 35.9 ± 4.1%, $p$ = 0.006; F     1 ),
,
.
,       27.8 ± 6.2% ($p$ < 0.001), 29.5 ± 6.5% ($p$ =
0.004),    21.7 ± 4.6% ($p$ = 0.004),        ,  .
I     0.69 ± 0.15 ($p_1$ = 0.022), 0.61 ±
0.11($p_1$ = 0.011),    0.87 ± 0.18 ($p_1$ = 0.25),
,    ,  ,          .
I      ,  ,
,    ,    ,

,                 ,,      ,  ,
,  ,                -
,      ,    (            ,
)      5°    ,       (MPI = 20.1
± 7.0%, $p$ = 0.016    35.9 ± 7.4%, $p$ = 0.002,
, . MPI                ).
I     0.45 ± 0.18 ($p_1$ = 0.003)
0.92 ± 0.20 ($p_1$ = 0.69),      , .
,       ,          10°    ,
,
,       (MPI = 31.6 ± 8.8%, $p$ = 0.008
28.4 ± 6.6%, $p$ = 0.006,       , ). H     I   ,
,   ,
, . H     ,
,    ,
,
,     ,          5°
(MPI = −0.5 ± 10.7%, $p$ = 0.96;  I = −0.12 ± 0.41, $p_0$ =
0.39)   10° (MPI = 5.5 ± 5.2%, $p$ = 0.34)    ,
.          ,
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,             ,
($t$ = 2.39, $df$ = 22, $p$ =

. I , I 0.23 ± 0.12 ($p_0 = 0.13$) , , , , , . I -, - , , , ($t = 4.236$, $df = 14$, $p =$ 0.001). , , , , , - - , , , , - , .

## Double training with learning and actuator at the same retinal location

I F 1 ,, , ( ,., 2008; ,., 2012; ,., 2013), , , , , . H , F 1 , , , - . , , , , , , . ,- , F 1 , *same* , , . ,, , , , , - - , *same* , , 5° , . , (MPI = 37.3 ± 3.5%, $p < 0.001$; F 2 ) , (MPI = 29.7 ± 5.4%, $p = 0.002$; F 2 ), , (MPI = 29.9 ± 3.0%, $p < 0.001$, ,, 18 F 2) , , , (MPI = 25.0 ± 3.8%, $p < 0.001$, 31.3 ± 5.1%, $p < 0.001$, , ). I 1.00 ± 0.20 ($p_1 = 0.50$) 0.99 ± 0.19 ($p_1 = 0.48$), , . H , , (MPI = 29.5 ± 5.2%, $p = 0.014$), , (MPI = −6.8 ± 12.9%, $p = 0.83$; I = −0.22 ± 0.41, $p_0 = 0.20$; F 1 ). H , -G , , - , 2AFC (F 2 - , ,, F 2 - , ; $n = 6$), , G - , 2AFC (F 2 - , ; $n = 5$). B , - , 2AFC , , - , 2AFC , ,. , , , , . A F 1, ,, I , , , ,

- , , ($t = 3.63$, $df = 20$, $p = 0.002$).

## Sequential double training and the effect of reversed order

O , , , ,- , , - , , - , , ,, - , - , . I , , , , , , ( & , 2005). , , , , (F 3 ). O , , (MPI = 34.0 ± 5.8%, $p = 0.002$), , , (MPI = −4.1 ± 5.1%, $p = 0.46$; I = −0.1 ± 0.16, $p_0 = 0.26$), , , - . (MPI = 25.7 ± 3.7%, $p < 0.001$).

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F , , 1994; ,., 1995; C ,., 1997;
B ,, ,., 2011). , , ,
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30 -4.8( 4;)-3 , - 31.9( 915- )-9450 D (, 7( - ( )-31. 3 1.9( )-31( , ,

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*Ke ords: percept al learning, transfer, do ble training, Vernier*

## Acknowledgments

N ,
F C G 31230030 (C )
31470975 (J ), N , I
H , G O1E 01728 O1E 04776
(DML & AK). L , , L ,
A , ,
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* J- ,, .
C , , : .
C : C ; J - .
E ,: @ . . ; , @ . . .
A : D P , , P -
, B , , C .

## References

A , M., & H , . (1997). , , , . *Nat re, 387*(6631), 401 406.

B ,,, K., & , , . (1987). D - . *Vision Research, 27*(6), 953 965.

B ,, , . ., B , J. M., L , . L., & P , A. (2011). P , , - , , . *Nat re Ne roscience, 14*(5), 642 648.

C , M. ., & M ,,, J. H. (2011). , , , , . *Ne ron, 70*(6), 1192 1204.

C , . E., K , M. K., , G., &

G , , C. D. (1997). P , , , , , : , , . *Jo rnal of Ne roph siolog , 78*(6), 2889 2894.

D , B. A., J , P., L , J., & L , . L. (2013). A , , - . *Proceedings of the National Academ of Sciences, U S A, 110*(33), 13678 13683.

D , B. A., & L , . L. (1999). M , , . *Vision Research, 39*(19), 3197 3221.

F , , M. (1994). H : P ,, , , , . *Perception, 23*(4), 411 427.

F , , M. (1997). , , , . *Vision Research, 37*, 1885 1895.

H , . C., & , A. . (2014). P , , , , . *Jo rnal of Ne roscience, 34*(25), 8423 8431.

J , P. E., D , B. A., P , A., & L , . L. (2009). , , . *Jo rnal of Vision, 9*(3):1, 1 13, :// ., , . / /9/3/1, : 10.1167/9.3.1. P M A ,

K , A., & , D. (1991). : E , , . *Proceedings of the National Academ of Sciences, U S A, 88*(11), 4966 4970.

L , J., L , . L., & D , B. (2011). M , -, , , ,, , . *Jo rnal of Vision, 11*(11): 992, :// . , , . / /11/11/992, :10. 1167/11.11.992. A

M - , ,, , J. C., & , . (2004). F - , , - , . *C rrent Biolog , 14*(9), 744 751.

M A , C. J., & M ,,, J. H. (2000). A , , - 4. *Jo rnal of Ne roph siolog , 83*(3), 1751 1755.

M ,, , J. D., & D , , M. . (1996). , , . *Spatial Vision, 10*(1), 51 58.

P , A. A., D , B. A., & L , . L. (2005). , , : A , ,. *Ps chological Re ie , 112*(4), 715 743.

, A., , , ., & O , G. A. (1995). H , , , : , - , . *Jo rnal of Ph siolog , 483(Pt 3),* 797 810.

, A., & , . (2005). A , , , . *Trends in Cogniti e Sciences, 9*(7), 329 334.

, L. P., & P , , H. (1992). I , ,, , , . *Perception & Ps cho- ph sics, 52*(5), 582 588.

, , M., L , ., & , J. (2013). A , , , , , , . *Jo rnal of Vision, 13*(1):7, 1 23, :// ., , . / /13/1/7, :10.1167/13.1.7. P M A ,

, ., C , L. J., & , C. (2013). , , D , , , , , . *Jo rnal of Vision, 13*(5):9, 1 9, :// ., , . / /13/5/9, :10. 1167/13.5.9. P M A ,

, ., , J. ., K, , . A., L , D. M., & , C. (2012). , , , - , - , , . *Vision Research, 61,* 33 38.

, L. Q., , J. ., , ., K, , . A., L , D. M., & , C. (2008). C , , , , , , . *C rrent Biolog , 18*(24), 1922 1926.

, C., K, , . A., & L , D. M. (2004). P , , ( - ,) , . *Jo rnal of Vision, 4*(3):4, 169 182, :// ., , . / /4/3/4, :10.1167/4.3.4. P M A ,

, E., , G. L., & L , . (2013). , , - , . *E ropean Jo r- nal of Ne roscience, 38*(12), 3758 3767.

, G. L., C , L. J., , ., & , C. (2013 ). E P C1 , , , , . *Jo rnal of Vision, 13*(9): 909, :// . , , . / /13/9/909, :10.1167/ 13.9.909. A

, G. L., C , L. J., , ., & , C. (2013 ). E P P1-N1 , , , . *Jo rnal of Vision, 13*(4):19, 1 13, :// ., , . / /13/4/19, :10. 1167/13.4.19. P M A ,

, J. ., C , L. J., K, , . A., L , D. M., & , C. (2014). P , , , , , - . *In estigati e Ophthalmolog & Vi- s al Science, 55*(4), 2020 2030, :// . . / /55/4/2020. P M A ,

, J. ., , ., K, , . A., L , D. M., & , C. (2012). P , , , , , : A . *Jo rnal of Vision, 12*(9): 1026, :// ., , . / /12/9/1026, :10.1167/12.9.1026. A

, J. ., & , . . (2014). P , - PE . *Vision Research, 99,* 93 98.

, J. ., , G. L., , L. Q., K, , . A., L , D. M., & , C. (2010). , - , , , , , . *Jo rnal of Ne roscience, 30*(37), 12323 12328.

, ., , L. Q., K, , . A., L , D. M., & , C. (2010). D , , , , . *Vision Research, 50*(4), 368 374.